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PERTHITE FROM TORY HILL, ONTARIO

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ABSTRACT

An unusually well-developed perthitic intergrowth of microcline and albite was discovered in pegmatite masses occurring in syenite near Tory Hill, Haliburton County, Ontario. The intergrowth is a composite of several textural varieties. The predominant type is composed of albite spindles developed parallel to the prism directions (110) and $(1\bar{1}0)$ in the microcline. The spindles or blebs along each of these crystallographic directions are arranged *en echelon* and the two sets are superimposed in such a manner as to result in braid-like veins which are approximately parallel to (100). Striking features of this perthite are the uniformity in orientation and size of the blebs, and the high percentage of the albite. The name, *braid perthite*, is introduced as a descriptive term for this textural type.

En echelon grouping of albite films (film perthite), as well as of the albite spindles of the braid perthite, is characteristic of the Tory Hill feldspar. This textural feature is also recognized in other perthites, and *en echelon* arrangements may be characteristic of early-formed blebs which by later processes are converted into solid veins or bands. In the Tory Hill perthite, vein or band perthite and patch perthite have been developed from the braid type by replacement. The feldspar components calculated from the chemical analysis of the Tory Hill feldspar are (weight percentages) Ca-f, 0.1; Na-f, 57.7; K-f, 42.2.

The crystallographic directions developed in the Tory Hill perthite are similar to those found in other perthites. It is believed that these directions are related to, and basically controlled by, the atomic structures of the interlaminated feldspars. Similarities between the Tory Hill feldspar and Ceylon moonstone are noted, and the origin of these perthitic feldspars may have points in common. Exsolution and replacement probably accompanied by recrystallization are the processes favored to explain the origin of the feldspar.

INTRODUCTION

In an investigation[1] of the igneous rocks of the Tory Hill stock in Haliburton County, Ontario, an unusual perthite was encountered. Striking features of this intergrowth are the uniformity in orientation and size of the albite blebs or spindles, and the unusually high proportion of this feldspar. Gradations from this regular intergrowth into less regular patterns are found and are believed to be significant, but the degree of perfection attained in the development of some of the Tory Hill perthite affords an example of regularity equal to, if not surpassing, any illustration in the literature.

Textural characteristics are significant factors in the theories suggested for the origin of perthites. For this reason, the first part of this paper is devoted to a rather detailed description of the Tory Hill perthite. A consideration of the textural features of this perthite and of the similarity of these features to those described by other writers suggests that, fundamentally, perthitic intergrowths are governed by the atomic structures of the component feldspars. This view is elaborated in the second portion of the paper.

TORY HILL STOCK

Tory Hill stock lies 20 miles southeast of Haliburton, Ontario. The general field relationships as mapped by Adams and Barlow,[2] are shown in Fig. 1. Nepheline syenite forms the outer border of the stock enclosing syenites. The syenites are alkalic and are characterized by soda-rich pyroxenes and amphiboles. Abrupt changes in mineralogical composition are common and result in transitions within short distances from rocks composed chiefly of feldspar to rocks made up largely of ferromagnesian minerals. The feldspars are orthoclase, microcline and albite-oligoclase. Microcline-perthites are abundant and commonly form the major portion of the feldspar content (Fig. 2; Plate II–E). Sphene is the chief accessory. Quartz was not observed in the thin sections studied.

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[1] Kinser, J. H., A petrographic study of the Tory Hill stock, Haliburton County, Ontario: *Master of Science Thesis, University of Minnesota,* **1937.**

[2] Adams, F. D., and Barlow, A. E., Geology of the Haliburton and Bancroft areas: *Geol. Surv. Can., Memoir* **6,** 1910.

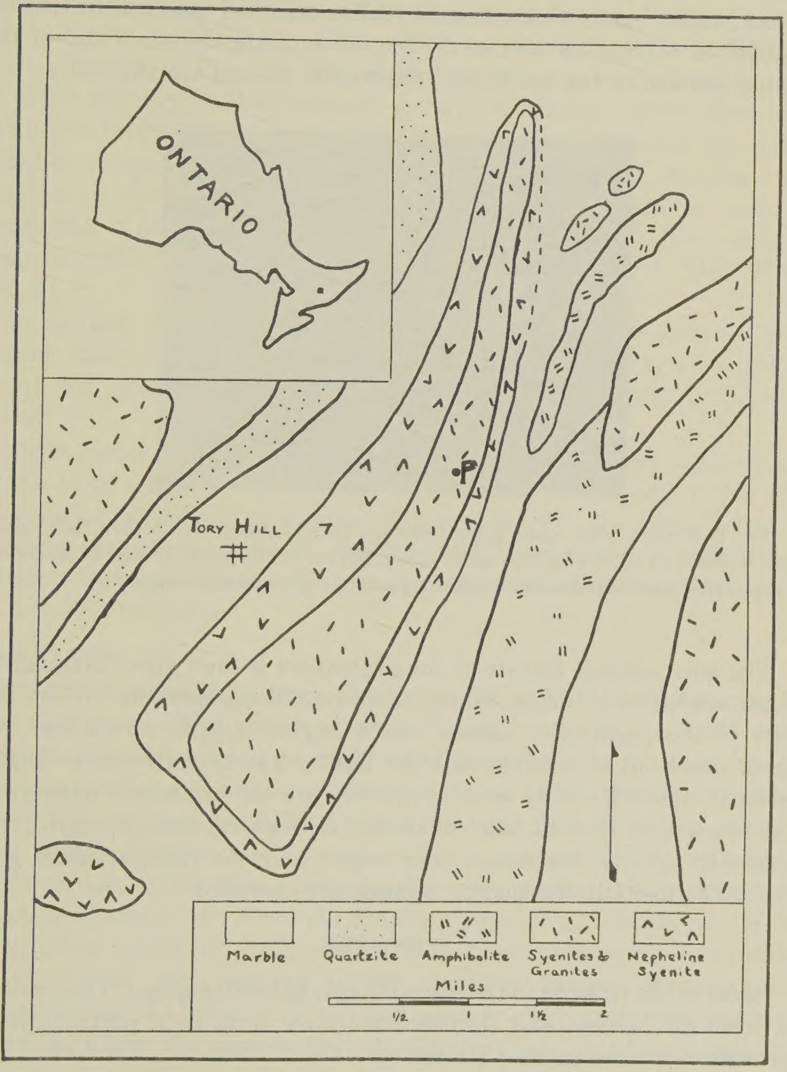

FIG. 1. Map of the Tory Hill area. Geology by Adams and Barlow. Location of perthite at point P.

Texturally, the syenites are coarse granular rocks usually somewhat trachitoid. The ferromagnesian minerals are stubby and show no marked tendency toward parallel alignment, but they do occur in more or less parallel bands which give the rocks a streaked appearance. Abrupt changes in texture, as well as in composition, are characteristic of the central portion of the stock, and pegmatitic masses are abundant.

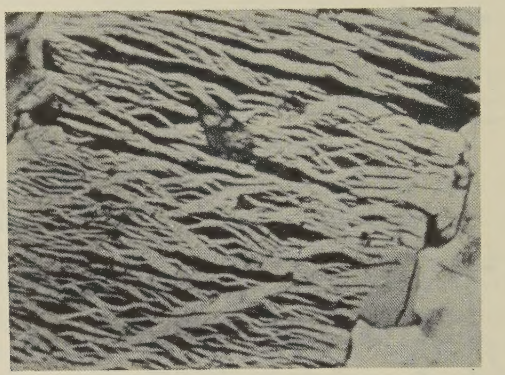

FIG. 2. Perthite from coarse-grained syenite, Tory Hill stock. Microcline, dark; albite, light. Crossed nicols. ×47. This regular intergrowth with exceptionally high albite content is regarded to have been formed, at least in part, by replacement (albitization).

The most notable feature of the pegmatites is their great irregularity. Some appear to be dikes; others, more nearly segregations. At the borders of the pegmatitic masses, black augite crystals about one inch thick stand out in contrast with the light colored country rock. Augite, feldspar, quartz, calcite and pyrrhotite are the abundant minerals in the pegmatites, and in large miarolitic cavities crystals of augite, feldspar and quartz are found. The augite and the feldspar show good crystal forms, but the quartz crystals are corroded.

PERTHITE

Most of the feldspar in the pegmatites is pale olive-green. This feldspar is fresh and glassy, and thin sections show it to be a perthitic intergrowth of microcline and albite.

TEXTURAL FEATURES

The perthite was studied in thin sections prepared from the basal (001) and brachy (010) cleavage fragments. The appearance of the intergrowth is quite different on the two pinacoids.

Braid Perthite

In sections parallel to (001), microcline, the potassic feldspar component of the perthite, is twinned in accordance with the albite and pericline laws and shows fine to coarse grating structure between crossed nicols. The albite is in braid-like veins which are approximately parallel to (100). The braids are composed of two superimposed *en echelon* groups of albite spindles or blebs oriented parallel to the unit prism directions (110) and $(1\bar{1}0)$. Polysynthetic twinning is not conspicuous in the albite spindles composing the braid, but the type of twinning described by Rogers[3] in the "peculiar" perthite from Port Henry, New York, is developed. The albite spindles parallel to (110) are in the twinning position (albite twinning) with respect to those parallel to $(1\bar{1}0)$, Plate I-A, II-A.

In sections parallel to (010), the albite appears as numerous lens-shaped veins which cut the trace of the basal cleavage at an angle of about 65°. Their elongation, therefore, is parallel to the vertical or c axis.

From measurements made on several thin sections, the composition of the braid perthite was estimated (Kinser) as 58 per cent albite and 42 per cent microcline, by volume. The regularity of the intergrowth in sections parallel to (001) is striking, and the pattern is sufficiently distinctive to warrant the name *braid* perthite which is here introduced as a descriptive term.

Film Perthite

In sections parallel to (001), small stringers or films of albite occur in the microcline. These rarely exceed 0.1 mm. in length and 0.004 mm. in width. The films trend parallel to the general direction of the braids and are parallel to (100). In sections parallel to (010), the films of albite are clearly seen and are differentiated from the vein albite not only by their smaller size but also by their different orientation. The direction of elongation of the films intersects the trace of the (001) cleavage at an angle of about 74°. Thus the films are parallel to a hemidome. This direction is typical of film perthite. Miller indices ranging from $(\bar{6}01)$ to $(\bar{8}01)$ have been assigned to the plane by various investigators. Spencer[4] gives the indices $(13.0.\bar{2})$ and refers to the plane as the perthite or schiller plane. He suggests that the different indices obtained indicate that the orientation of the plane varies with the composition of the feldspar. The schiller plane is undoubtedly the murchisonite parting of some writers.

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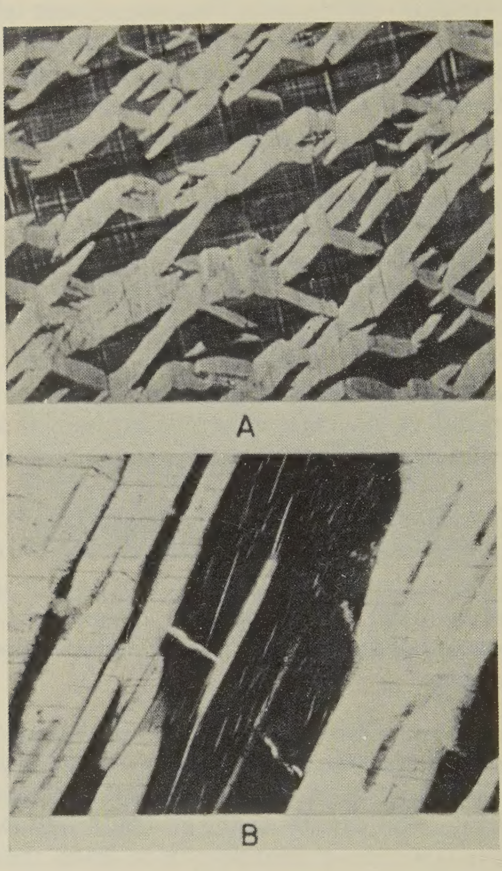
[3] Rogers, A. F., Observations on the feldspars: *Jour. Geol.*, **21,** 202–203 (1913).

[4] Spencer, E., A contribution to the study of moonstone from Ceylon and other areas and of the stability-relations of the alkali-felspars: *Mineral Mag.*, **22,** 309 (1930).

PLATE I



Tory Hill perthite.
(Crossed nicols. ×66)

A—Section parallel to (001). Braid perthite. The film perthite is obscured by the cross-hatching in the microcline.

B—Section parallel to (010). Microcline, dark; albite, light. Details in the large microcline vein: (1) *en echelon* arrangement of the minute albite films results in groups of films which are parallel to the direction of vein development; (2) a faintly visible vein of sodic feldspar, "phantom" perthite (lower central portion of large microcline vein), contains well-developed albite films suggesting that the *en echelon* groups may be a controlling factor in the development of the vein perthite.

A study of the film perthite under high magnifications shows that the albite films or strings are commonly arranged *en echelon* (Plate I-B). The groups thus resulting trend parallel to the direction of the larger albite veins, suggesting a relationship between the film and vein perthite. This view is further supported by the presence of well-developed *en echelon* groups of albite films within "phantom" veins of sodic feldspar. These veins are not clearly seen in transmitted light, but become visible between crossed nicols.

Vein Perthite

In certain thin sections prepared from the Tory Hill perthite parallel to (001) a transition from braid perthite to ordinary vein or band perthite is noted. These veins are formed by replacement of the microcline in the re-entrant angles formed by the intersection of the albite spindles making up the braid. The veins are parallel to (100) and for this reason cannot be distinguished from the braids in sections parallel to (010). Polysynthetic twinning is well developed in the albite (Plate II-C).

Patch Perthite

By further replacement of microcline by albite, braid and vein perthite grade into typical patch perthite (Plate II-D). The contacts between the microcline and the albite are irregular and islands of microcline of irregular shapes are present in the albite. The twinning lamellae in the albite are sharply defined but are not continuous, a peculiarity of albite in this type of perthite (chess-board albite).

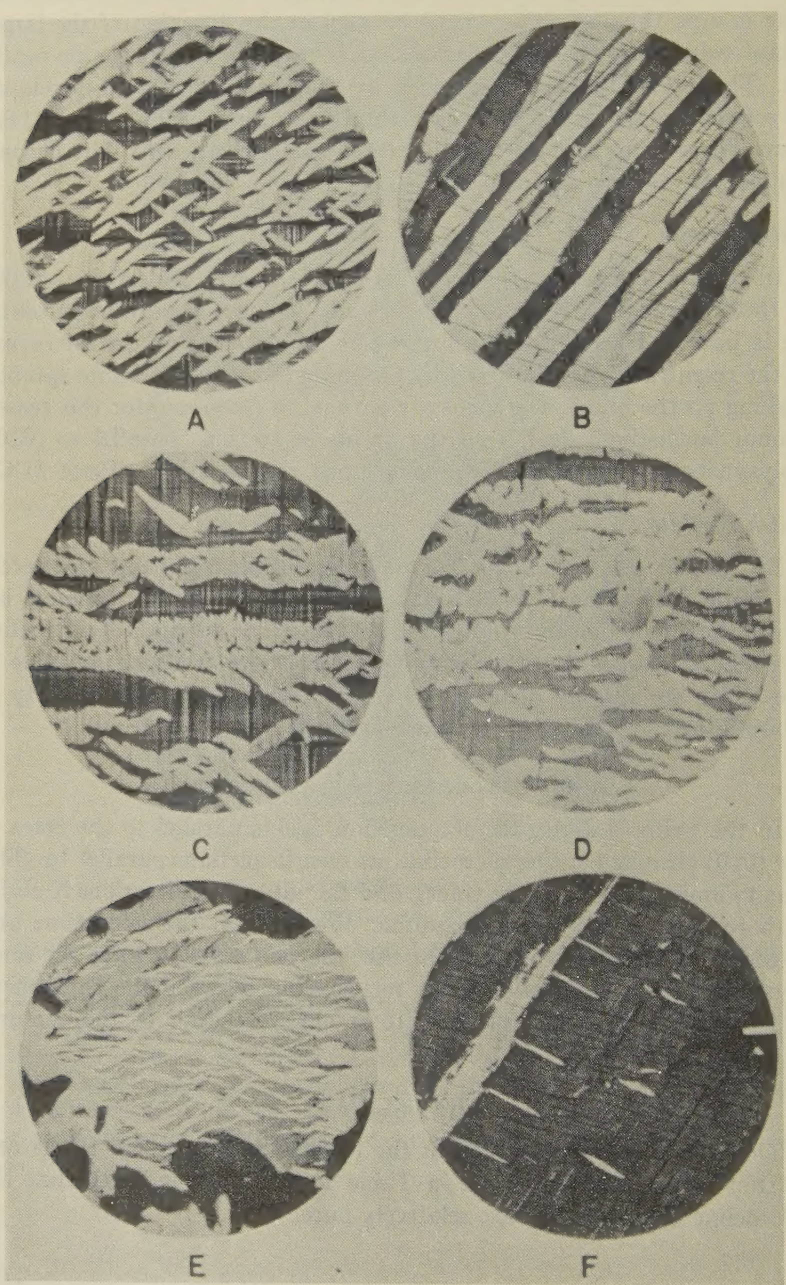
Crystallographic Relationships

In the twinned albite the composition face is parallel to the trace of the (010) cleavage of the microcline, as seen in sections parallel to (001) The twinning, the cleavage traces, and the vibration directions X and Z with relation to the crystallographic directions in the microcline and in the albite show beyond a doubt that the two minerals have the same crystallographic orientation. This relationship between the component feldspars of the Tory Hill perthite is noted in each of the textural varieties.

Optical Data

The results of optical study of the feldspar in immersion media and in thin section are presented in Table 1. The data indicate that the microcline and the albite are relatively pure.

Plate II



Textural varieties.

A—Tory Hill perthite. Section parallel to (001). Regular development of braid perthite. The *a* axis is vertical. Crossed nicols. ×32

B—Tory Hill perthite. Section parallel to (010). Crossed nicols. ×32

C—Tory Hill perthite. Section parallel to (001), showing transition from the braid perthite to vein or band perthite. Crossed nicols ×32.

D—Tory Hill perthite. Section parallel to (001), showing transition to patch perthite. Crossed nicols ×32.

E—Microcline-perthite in syenite from Tory Hill stock. Microcline, dark; albite, light. Crossed nicols × 32.

F—Microcline-perthite from granite pegmatite, Granite Mountain, Texas. Section parallel to (010). Crossed nicols. ×64. Poikilitic albite, vein perthite, film perthite, and an unnamed variety in which the blebs make an angle of about 12° with the trace of (001).

TABLE 1. OPTICAL CONSTANTS OF FELDSPARS IN TORY HILL PERTHITE

	Albite	Microcline
INDICES:		
Alpha	1.526	1.517
Beta		1.522
Gamma	1.537	1.524
EXTINCTION ANGLES:		
On (010)	19°	5°
On (001)	4°	17°

CHEMICAL DATA

A chemical analysis of the perthite was made in the Rock Analysis Laboratory of the University of Minnesota and is given in Table 2. An analysis by Warren[5] of perthite from the type locality, Perth, Ontario, is also included in the table. The small lime content of the Tory Hill feldspar is noteworthy and supports the optical data. The components calculated from the analysis are Ca-f and Ba-f, 0.1; Na-f, 57.7; and K-f, 42.2.

TABLE 2. CHEMICAL ANALYSES

	1	2
SiO_2	66.56	66.50
Al_2O_3	19.04	18.40
Fe_2O_3	0.41	1.05
FeO	0.18	
MnO		tr.
MgO	0.00	0.07
CaO	0.01	0.30
BaO	0.02	
Na_2O	6.77	5.40
K_2O	7.09	8.77
H_2O+	0.10	0.20
H_2O-	0.02	
	100.20	100.69
Sp. Gr.	2.593*	2.597
Ca-f Ba-f	0.1	1.5
Na-f	57.7	46.2
K-f	42.2	52.3

* 28°/4°.

1—Perthite from Tory Hill stock, S. S. Goldich, *analyst.*

2—Perthite from Perth, Ontario, C. H. Warren, *analyst. Proc. Am. Acad. Arts and Sci.,* **51,** 139 (1915).

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[5] Warren, C. H., A quantitative study of certain perthitic feldspars: *Proc. Am. Acad. Arts and Sci.,* **51,** 139 (1915).

IMPURITIES

Very small amounts of minerals other than the feldspars are present in the Tory Hill perthite. A few thin bands of an undetermined green mineral are oriented with their long dimension parallel to (010). In sections parallel to (010), small narrow plates of a colorless mineral occur along the (001) cleavage cracks in the albite, but are essentially lacking in the microcline. This mineral shows strong birefringence and a marked change in relief on rotation of the stage. It is probably muscovite and appears to be oriented in the albite so that the basal pinacoids of the two minerals coincide.

COMPARISON OF TORY HILL INTERGROWTH WITH OTHER PERTHITES

The Tory Hill feldspar is a composite of several textural varieties exhibiting the general characteristics of perthites from other localities.

PERTH, ONTARIO, INTERGROWTH

Rogers[6] called attention to the tendency of the albite blebs, in sections parallel to (001), to coalesce in such a manner as to practically form solid plates along directions parallel to (110). Dittler and Köhler[7] noted the presence of albite films in this perthite. They state that the direction of development is parallel to the murchisonite parting, making an angle of about 74° with the trace of (001) in sections parallel to (010). Thus, the directions developed in the Tory Hill perthite are found in the intergrowth from the type locality.

AMBALANGODA MOONSTONE

Spencer[8] found two types of perthitic structures in the moonstone from a weathered pegmatite near Ambalangoda, Ceylon,—a fine regular variety designated (or,ab) microperthite or cryptoperthite, and a coarser (Or,Ab) "shadow" or "lattice" perthite. In sections parallel to (001) the lamellae of the fine (or,ab) microperthite are parallel, for the most part, to the trace of (100), but also branch off in directions corresponding to (110) and (320). On (010) the lamellae (0.05 mm. in length and from 0.0005 to 0.001 mm. in thickness) make an angle of about 73° with the basal cleavage. According to Spencer the plane of (or,ab) microperthite development is the perthite plane, or the plane of schiller with the Miller indices $(13.0.\bar{2})$. The (Or,Ab) "shadow" perthite was so named because it is clearly visible only between crossed nicols. The directions developed in this perthite are not well defined, but are said to be mainly along the planes (110) and (320).

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[6] *Op. cit.*, p. 203.

[7] Dittler and Köhler, A., Zur Frage der Entmischbarkeit der Kali-Natronfeldspäte und über das Verhalten des Mikroklins bei hohen Temperaturen: *Tscherm. Min. Petr. Mitt.*, **38**, 243 (1925).

[8] *Mineral. Mag.*, **22**, 297 (1930).

Spencer has called attention to the similarity of Rogers' "peculiar" perthite and the Ceylon moonstones. He pointed out that the "principal plane of perthite separation is in both cases the unit prism instead of the usual perthite plane."

GRANITE MOUNTAIN, TEXAS, PERTHITE

A microcline-perthite from a granite pegmatite at Granite Mountain, Texas, will serve to illustrate certain textural characteristics of perthites. In Figure F of Plate II, taken of a section parallel to (010), albite is shown in four distinct relations.

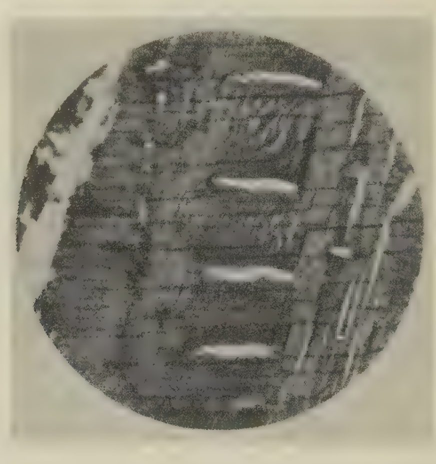

FIG. 3. Microcline-perthite from a granite pegmatite, Granite Mountain, Texas. Section parallel to (010). Crossed nicols. × 82. Film and vein perthite, together with a third type in which small blebs making an angle with (001), form *en echelon* groups. The blebs tend to flatten out in a direction parallel to the trace of the basal cleavage, which is the direction taken by the groups. An absence of albite films in the immediate areas of this type of perthite is conspicuous.

(1) Poikilitic albite, crystals of random orientation are included in the microcline-perthite.

(2) Strings or films of albite with the usual orientation make an angle of about 74° with the trace of the basal cleavage which can be seen as many parallel cracks inclined slightly from a horizontal position in the photomicrograph. A second set of cracks not nearly as well developed as those forming the trace of the basal cleavage, are parallel to the direction of film development and probably represent the so-called murchisonite parting.

(3) Veins of albite, irregular in size and shape, are mainly parallel to the *c* axis and intersect the basal cleavage at an angle of about 66°.

(4) Albite spindles measuring about 0.1 mm. in length and being distinctly larger than the albite films, appear to be related to the direction (001), but actually the direction of the blebs intersects the trace of (001) at an angle of about 12°. Although rare and as yet unnamed, this type of albite development is probably deserving of the rank of a textural variety. Warren[9] has described a perthite from Westfield, Massachusetts, in which small lamellae of albite make an angle of about 12° with the basal cleavage of the microcline in sections parallel to (010).

Figure 3 is a photomicrograph of a section of the Texas perthite parallel to (010) which also shows the film and vein perthite, but of particular interest is the development of the albite blebs related to (001). It is significant that the blebs are *en echelon*, the individual blebs intersecting the trace of the basal cleavage, but the group as a whole is essentially parallel to (001).

ORIGIN OF PERTHITES

It is noteworthy that each of the prominent crystallographic directions developed in perthitic intergrowths appears to be parallel to a plane of parting or of cleavage in the feldspars. It is not surprising that attempts to explain the orientation of the blebs by many writers have been based upon a correlation of perthite directions with planes of weakness in the feldspars. Such a relationship exists, but the fundamental significance of this relationship has but recently been appreciated.

Contraction Cracks

The origin of perthites, it has been held, is connected in some manner with the phenomenon of contraction. Dittler and Köhler[10] found that the determined molecular volume of anorthoclase is about $\frac{1}{2}$ per cent greater than the volume calculated on the basis of the feldspar components contained. They suggested that the unmixing of anorthoclase to form perthite is related to contraction. Lehmann[11] has suggested that perthites are formed in connection with contraction cracks. He claimed that by chilling feldspars in water, contraction cracks are developed more abundantly parallel to (100) and parallel to the prism faces (110) and $(1\bar{1}0)$, than to the better cleavages (001) and (010). Brøgger[12] in his investigations of the perthites and cryptoperthites of Norway, suggested that these perthites were formed in connection with secondary planes of parting parallel to (100) and parallel to $(\bar{8}01)$ (the murchisonite parting). Andersen[13] has developed an elaborate contraction-crack theory and regards such cracks as the controlling factor in the development of vein perthite, and possible also in film perthite. His view is that cracks should develop most prominently in a plane perpendicular to (010) and making an angle of about 70° with (001). This direction is not far removed from the plane of schiller, or from the murchisonite parting.

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[9] *Op. cit.*, p. 131.

[10] *Op. cit.*, p. 260.

[11] Lehmann, J., Über die Mikroklin- und Perthitstructur der Kalifeldspäthe und deren Abhängigkeit von äusseren, z. Th. mechanischen Einflüssen: *Jahresber. Schles. Ges. vaterl. Kultur*, **63**, 92–100 (1895); **64**, 119 (1896).

The openings made available along cracks, which may indeed be contraction cracks, are no doubt of importance in the development of certain perthitic feldspars, but there is much evidence suggesting that there is a more fundamental control in the atomic structures of the interlaminated feldspars.

STRUCTURAL CONTROL

A basic structural control in the development of perthites not only affords a logical explanation for the preferential or selective directional development, but also presents an explanation for the observed relationship between the perthite directions and planes of parting and cleavage, which similarly are dependent upon the crystal structure of the feldspars.

X-ray Data

Warren[14] should probably be given credit for anticipating a structural explanation for perthitic feldspars. Taylor[15] has made a definite contribution along this line. In applying data obtained in an *x*-ray investigation of sanidine and albite, Taylor points out that the *a* axes are quite different in the two crystals (8.45 Å in sanidine, 8.14 Å in albite), but the *b* and *c* axes are remarkably similar (12.90 Å and 7.15 Å, respectively in sanidine, and 12.86 Å and 7.17 Å in albite). A tetrahedron framework continuous throughout the lamellae of perthites and cryptoperthites is visualized. Greater and lesser extensions of the chains in the regions of potassic and of sodic feldspar result in the lamellae which appear optically as the two components of the perthite. Taylor is adverse to further speculation on the basis of the data now available.

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[12] Brøgger, W. C., Die Mineralien der Syenitpegmatitgänge der Südnorwegischen Augit- und Nephelinsyenite: *Zeits. Kryst.*, **16,** 521–564 (1890).

[13] Andersen, O., The genesis of some types of feldspar from granite pegmatites: *Norsk. Geol. Tidsskrift,* **10,** 116–209 (1928).

[14] *Op. cit.*, p. 149.

[15] Taylor, W. H., Darbyshire, J. A., and Strunz, H., An *x*-ray investigation of the felspars: *Zeits. Krist.*, **87,** 464–498 (1934).

It has been noted, however, that the important crystallographic directions developed in perthitic intergrowths are parallel to directions of cleavage or of parting. The good cleavage in sanidine takes place through the weak potassium-oxygen bonds. The positions of the potassium atoms in the structure are in themselves inadequate in explaining perthite orientations. The plane (001), for instance, appears to be of secondary importance. Nevertheless, some clue to the development of film perthite and of the possible relationship between albite films and albite veins may possibly be seen in the positions of the potassium atoms. In Fig. 4 the directions of film and vein developments have been superimposed upon a projection of potassium atoms on (010) for sanidine. A detailed structural analysis of the perthite directions or planes is needed.

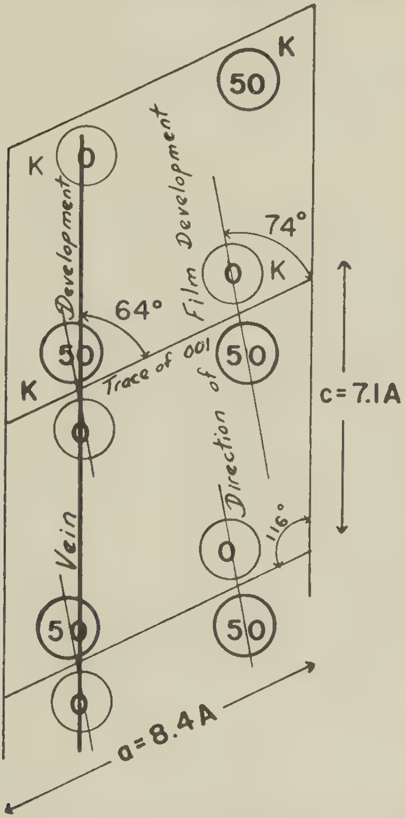

FIG. 4. Relations of film and vein perthite developments to the positions of potassium atoms in sanidine projected on (010). The projection is only approximate and was adapted from Fig. 130, Bragg's *Atomic Structure of Minerals*, p. 235.

Overgrowths

Royer,[16] Frondel and Ashby,[17] and Pabst[18] have demonstrated that there is a structural explanation for overgrowths as well as for intergrowths of certain minerals. Structurally similar planes are shared, and these planes determine the orientation.

Miers and Bowman[19] describe and figure an overgrowth of albite crystals on orthoclase. The albite crystals are shown in parallel arrangement on the prism faces of the potash feldspar, and it is stated that the prism zones coincide and that the faces (010), (110), and $(1\bar{1}0)$ are approximately parallel to each other.

Optical Continuity

In support of his hypothesis that vein perthite in granite pegmatites is formed by the simultaneous crystallization of the albite and microcline, Spencer[20] writes:

> "In most specimens the "vein" perthite is in optical continuity with the microcline, i.e., the albite-twin lamellae of the perthite lie parallel to those of the microcline. One would expect this to be the case if crystallization of the microcline and perthite had been simultaneous, but not necessarily so if the albite were of later infiltration origin."

One of the features of perthites observed by the writers which was considered worthy of special attention and which is best explained in terms of structural control, is that in perthites of different modes of origin, the sodic and potassic feldspars are in parallel crystallographic orientation, or as Spencer terms it, in optical continuity. It may be that the writers' observations are too limited in this respect, but in the Tory Hill feldspar several textural varieties are recognized and in each the albite is in parallel crystallographic orientation with the microcline, just as it has been found to be in vein and patch perthites from granite pegmatites.

PROCESSES

In extending the idea of a basic atomic structural control in the development of perthitic intergrowths, the writers contend that the mode of origin influences the rigidity of control, thus giving rise to the textural varieties which have been recognized. That perthites are of different origins is well recognized, and at least three processes are supported in the literature. These are (1) exsolution, (2) simultaneous crystallization, and (3) replacement. Obviously a wide range of conditions may be expected, and variables to be considered are temperature, pressure, concentrations, and time. Optimum conditions for rigid structural control are probably approached in exsolution. Likewise, the simultaneous crystallization of two feldspars in an oriented intergrowth, assuming such a process is possible, would take place under conditions highly favorable to rigid structural control. Early-formed crystals react with magma to produce uniform crystals of different composition. Such magmatic reactions grade into deuteric alteration, and the line demarking deuteric alteration from high temperature replacements which are hydrothermal is truly an elusive one. However, under conditions of relatively low temperatures and with highly aqueous rather than magmatic concentrations, it is not difficult to visualize a sloughing-off of structural control with increasing importance being relegated to openings and ease of circulation. Atomic structure remains an important factor under such conditions in influencing or determining the location of the openings. These views, the writers believe are essentially those propounded by Andersen,[21] except that primary importance is here attached to the control of atomic structure rather than to contraction cracks to explain the orientations of the lamellae.

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[16] Royer, M. L., Recherches expérimentales sur l'épitaxie ou orientation mutuelle de cristaux d'espèces différentes: *Bull. Soc. Fran. Min.*, **51**, 7–151 (1928).

[17] Frondel, C., and Ashby, G. E., Oriented inclusions of magnetite and hematite in muscovite: *Am. Mineral.*, **22**, 104–121 (1937).

[18] Pabst, A., Orientation of bixbyite on topaz: *Am. Mineral.*, **23**, 342–347 (1938).

[19] Miers, H. A., *Mineralogy*, 2nd Ed., revised by H. L. Bowman, pp. 266, 522, Macmillan and Co., Ltd., *London*, **1929.**

[20] Spencer, E., The potash-soda-felspars. Part II. Some applications to petrogenesis: *Mineral. Mag.*, **25**, 107 (1938).

The writers should like to emphasize that under conditions favorable to structural control, it seems quite probable that intergrowths of rather similar appearance could result from all three suggested processes. If such be the case, optical continuity, regularity of pattern, and even, size, distribution, and orientation of blebs, may be of little avail as criteria for determining the process of formation of certain perthites.

The literature affords many examples of differences of opinion as to the origin of specific perthites. In all fairness, it should also be said that textural differences are not the sole reason for seeking different genetic processes to explain different perthites. Genetic theories and experimental data have played a considerable part, and the problem is a complicated one. A brief speculation as to the origin of the Tory Hill perthite may serve to bring out a few of the difficulties.

Application to Tory Hill Perthite

The Tory Hill perthite is a composite of several textural varieties. The genesis of these varieties may be distinct and unrelated, but it appears equally probable that the development may have been continuous with the evolution of the textural varieties dependent upon a gradually changing physical environment.

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[21] *Op. cit.*, p. 162.

Of the textural varieties in the Tory Hill perthite, film perthite has generally been assigned to exsolution; patch perthite, to replacement. The evidence for these assignments need not be reviewed here, but if both of these processes have been operative, an important question arises. This is whether the braid and vein perthites represent one or both of these processes or the third process, that of simultaneous crystallization. In review of the properties of the braid perthite, the following points are significant.

1. The braid perthite represents a strikingly regular arrangement of albite spindles oriented parallel to (110) and $(1\bar{1}0)$. *En echelon* groups are superimposed one on the other to form the braid which is approximately parallel to the trace of (100).
2. The albite and microcline are in optical continuity.
3. Polysynthetic twinning is poorly developed in the albite spindles and is entirely lacking in many.
4. Measurements on several thin sections of the regular braid perthite indicate about 58 per cent of albite by volume.
5. The braid perthite appears to grade into a variety designated as vein or band perthite.

If an origin by simultaneous crystallization of albite and microcline is assumed for the braid perthite, the history of the development may be postulated. Contemporaneous crystallization of albite and microcline containing a small amount of soda feldspar in solid solution resulted in the braid perthite. Subsequently, albite films were developed in the microcline by exsolution. Patch perthite was later developed by replacement. Difficulty arises in explaining the vein perthite which is a transition type between the braid and the patch perthites. This variety most nearly resembles the vein perthite characteristic of granite pegmatites attributed by Spencer to simultaneous crystallization. Polysynthetic twinning in the albite is well developed; the microcline is coarsely twinned, and the two feldspars are in optical continuity. The writers believe this vein or band perthite to represent replacement, and although the simplicity of the explanation given above for the development of the Tory Hill perthite is appealing, a more complicated history is indicated.

Attention has been called to the similarity of the Tory Hill perthite to Ceylon moonstone, especially in the crystallographic directions developed. Spencer[22] has demonstrated that the moonstones represent orthoclase-microperthites and cryptoperthites formed by exsolution. His explanation of the genesis of the Ambalangoda moonstone may have application to the origin of the Tory Hill perthite. The textural relations have been briefly described in a preceding section. According to Spencer, two solid-solution changes have occurred in the moonstone. A single solid-solution phase first separated into (Or,Ab) perthite at about 900–1000°C. The (Or) and (Ab) phases, representing solid solutions containing different proportions of potash and soda feldspar components, are believed to have had rather similar physical properties. The (or,ab) microperthite and cryptoperthite separated from the (Or) and (Ab) phases at about 500–700°C. and developed mainly along the plane of schiller $(13.0.\bar{2})$. As a consequence of this second solid-solution change the (Or) and (Ab) phases no longer existed. They are recognizable now only because there are different proportions of (or) and (ab) in the areas of the original (Or) and (Ab) phases.

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[22] *Mineral. Mag.*, **22**, 291–368 (1930).

The moonstones constitute an orthoclase-microperthite series with a soda-feldspar content ranging from 4 to 52 per cent. If the many albite strings and films in the soda-rich moonstone from Ceylon were gathered into areas of pure albite, and the orthoclase into areas of relatively pure potash feldspar containing a few residual films of albite, and if during this process, the orthoclase were converted to microcline, the result would be a braid-like perthite similar to the Tory Hill perthite. If also, subsequent to this process and possibly as a direct continuation of magmatic processes, deuteric or hydrothermal alteration occurred with albitization of the early-formed feldspar, the braid perthite would be converted in part to vein or band perthite, passing finally into patch perthite. The orthoclase-microcline relationships are but little known, and the writers are hesitant in advancing any details of the processes, but certain observations may be cited which support the generalized origin presented.

Spencer[23] has described a microcline-microperthite from a pegmatite in the vicinity of the Ambalangoda moonstone mine. This intergrowth has a bulk composition of 76.5, K-f; 20.4, Na-f; 3.1, Ca-f. The perthitic structure is described as being regular but much coarser than in the moonstone microperthite. The separation of the albite lamellae is said to be more complete, and this fact is correlated with the conversion of the feldspar to microcline. The change is said to have taken place probably at temperatures above 700°C. from a single homogeneous potash-soda-feldspar phase and was accompanied by complete exsolution of the soda-feldspar component in the form of albite lamellae which are oriented for the most part along the perthite plane, but also in part along (010).

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[23] Spencer, E., *Mineral. Mag.*, **22,** 327–330 (1930).

The moonstones or members of the orthoclase-microperthite series are readily homogenized by heat-treatment. In comparison with the moonstones, the microcline-microperthites were found by Spencer[24] to be resistant to heat-treatment, but the finely twinned microclines much less so than the coarsely twinned varieties. These experimental data are, in part, the basis for assigning the moonstones to an exsolution origin and the microcline perthites to simultaneous crystallization. Spencer emphasizes the fact that multiple twinning in the vein albite and the coarse twinning in microcline indicate that a rigid triclinic symmetry has been developed in these feldspars. He points out that multiple twinning is not present in the albite films of exsolution origin. The absence of multiple twinning in many of the albite blebs making up the braid perthite and the association of this albite with finely twinned microcline is suggestive, at least if the above criteria are accepted, that braid perthite may, in some manner, be connected with exsolution from a phase which originally was of monoclinic or near monoclinic symmetry.

To complete the round of suggestions, certain observations are presented which indicate a possible origin of the braid perthite, at least in part, by replacement.

1. Transition of the braid perthite into vein and patch types establishes replacement as an operative process in the history of the perthitic development.

2. Perthitic feldspars are common in the syenites intimately related to the pegmatite. Two photomicrographs (Plate II-F, and Fig. 2) illustrate these perthites. The amount of albite in the perthites ranges from a few stringers, which appear to be related to a marginal development of albite on microcline, to a marked preponderance of the soda feldspar. There is little doubt but that these perthites, in part at least, represent replacement, probably deuteric or high-temperature hydrothermal. Veinlets of molybdenite and pyrrhotite in the syenites support this view. However, it is interesting to note that there is an absence of multiple twinning in the albite lamellae.

An alternate suggestion, therefore, is that the braid perthite may have originated, in part, by the process of exsolution and, in part, by replacement. Andersen[25] has shown that there are textural transitions between string perthites and vein perthites. He believes that vein perthite may be formed from string perthite by a process of recrystallization which involves both the microcline and the albite strings. As a result the microcline loses its fine twinning and becomes the ordinary cross-twinned variety. The recrystallization, according to Andersen, is governed by contraction cracks and by fluxing agents. Usually the recrystallization is accompanied by addition of soda feldspar, and transitions from vein perthite into chess-board albite are common.

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[24] *Mineral. Mag.*, **22**, 363–364 (1930); **24**, 480–486 (1937).

[25] *Op. cit.*, p. 165.

The Ambalangoda moonstone represents a high-temperature feldspar which by exsolution on relatively rapid cooling resulted in orthoclase-microperthite and cryptoperthite. The Tory Hill feldspar with its high soda feldspar content and regularity of pattern bearing similarities to the moonstone may represent a microperthite of very similar magmatic origin. However, subsequent to the initial crystallization, a more complicated history is indicated than in the case of the moonstones. The idea of recrystallization under near-magmatic conditions possibly accompanied by replacement seems a reasonable one to the writers to account for the origin of the braid perthite. The vein and patch perthites were formed by replacement. This process may have been a continuation of magmatic processes and was accompanied by the development of rigid triclinic symmetry in both the sodic and potassic feldspar components.

ACKNOWLEDGMENTS

This study was initiated at the University of Minnesota where the preliminary investigation (J.H.K.) was conducted under Professor F. F. Grout. The writers are grateful for the courtesy extended in the use of the equipment of the Rock Analysis Laboratory of the University of Minnesota. All samples were collected by Kinser who also prepared the thin sections. The photomicrographs illustrating the present paper were made (S.S.G.) at the Agricultural and Mechanical College of Texas. Dr. William Parrish of the Massachusetts Institute of Technology plans to continue this investigation along the lines of structural analysis. His interest as well as that of others in the problem of the perthites is gratifying to the writers.

AMMONIUM MICA SYNTHESIZED FROM VERMICULITE

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Introduction

The "Action of hydrogen peroxide on weathered mica" was described very recently by Drosdoff and Miles.[1] These investigators noticed that treatment of soil samples with H_2O_2 to destroy organic matter caused the exfoliation of decomposed mica. They ascribed this reaction to the presence of traces of catalytic MnO_2 chiefly, which caused the decomposition of H_2O_2. The liberated oxygen forced the sheets of the mineral apart. They also found that the addition of a few drops of ammonium hydroxide accelerated the reaction considerably. The writer repeated these experiments and extended them to analyzed vermiculites with the idea of introducing between the layers ions which would restore the structure to the original one, which was that of biotite in most cases.

The structures of vermiculite and hydrobiotite (decomposed mica) have been described by the writer.[2] Hendricks and Jefferson[3] have confirmed the correctness of these structures recently. Though their description seems to differ, due to the choice of the *c* axis, it is actually the same, as they have pointed out.[4] They also have shown that the H_2O molecules probably occupy definite positions, and that vermiculite proper may be interstratified with chlorite units which would escape detection in a structure analysis. The present investigation finds strong support for this statement, as will be shown. The writer enjoyed the collaboration of Dr. R. B. Ellestad, who not only carried out the ammonia analyses but also gave much thought and time to the problem. Mr. Lynn Gardiner also assisted the author. The Graduate School of the University of Minnesota generously provided funds.

Experiments

Many experiments were made, of which a limited number will be described. After certain preliminary tests, analyzed specimens of vermiculite were used. These were identical with those described in the structure analysis cited,[5] with one addition. The analyses are repeated here under the same numbers as were used before. Additional information will be found in the paper mentioned. Unfortunately the analyzed material available was limited in quantity which made an ammonium analysis, for example, of No. 5 (Table 1) impossible.

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[1] Drosdoff, M., and Miles, E. F., *Soil Sci.*, **46**, 391–393 (1938).

[2] Gruner, J. W., *Am. Mineral.*, **19**, 557–575 (1934).

[3] Hendricks, S. B., and Jefferson, M. E., *Am. Mineral.*, **23**, 851–862 (1938).

[4] See the last paragraph of their paper.

[5] Gruner, J. W., *op. cit.*

TABLE 1. ANALYSES OF VERMICULITES BEFORE AND AFTER TREATMENT WITH NH_4OH

	1		4	5	6	V[2]
A. SiO_2	36.12		35.92	36.54	34.92	33.30
TiO_2	0.24				0.60	1.02
Al_2O_3	13.90		10.68	16.96	13.06	14.72
Fe_2O_3	4.24		10.94	2.78	2.74	5.02
FeO	0.68		0.82	0.95	0.54	1.36
NiO	0.28		none	2.32	3.24	2.14
MnO	trace					
MgO	24.84		22.00	19.78	23.92	22.00
CaO	0.18		0.44	0.06	0.24	0.12
K_2O						
Na_2O						
Total H_2O	18.94		19.84	20.40	20.30	19.36
H_2O 110°	(−130°) 8.20		10.50	9.24	9.00	8.56
H_2O 110°–400°	11.6[3]		4.34	3.80	5.00	4.94
H_2O Red heat			5.00	7.36	6.30	5.86
Total	99.42		100.64	99.79	99.56	99.04
B. Spacing of d_{001} before exp.	28.42 Å		28.46	28.38	28.46	28.62
C. Spacing of d_{001} after exp.	20.62		20.43	20.58	20.69	20.51
D. d_{001} after bomb exp.		20.51				
E. Spacing after 48 hours at 300°C.	20.41			20.48		
F. Spacing after 24 hours at 650°C.	18.51			18.49		
Analysis of Alteration Product						
G. NH_4	1.6	2.1	2.4		2.0	2.3
H. H_2O below 300°C.	3.9	1.9	2.4		3.0[1]	2.4
I. Total ignition loss	15.4	13.5	12.3		16.0[1]	13.6
J. Total loss minus NH_4	13.8	11.4	9.9		14.0	11.3
K. Apparent loss of H_2O during experiment	5.1	7.5	9.9		6.4	8.1
L. Indices before exp.		α 1.525 γ 1.545	α 1.532 γ 1.573		α 1.522 γ 1.55	
M. Indices after exp.		α 1.54+ γ 1.57+	α 1.56 α 1.59		α 1.55 γ 1.58	

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[1] Only 20 mg. available.

[2] Vermiculite from Webster, N.C., Analysis No. 5; C. S. Ross, E. V. Shannon and F. A. Gonyer: *Econ. Geol.*, **23**, 536 (1928). Also used by Hendricks and Jefferson under #5, *Am. Mineral.*, **23**, 855 (1938).

[3] Loss between room temp. and 300°C.

A small amount (less than 0.2 gram) of material was placed in a beaker and covered with about 5 to 7 cc. of 30% hydrogen peroxide. A few drops of NH_4OH were added. Very soon a vigorous reaction could be observed due to the decomposition of H_2O_2. After some hours exfoliated worm-like aggregates could be seen. After about 10 to 20 hours no more exfoliation was noticeable. Usually the beakers were kept on a warm steam radiator for about 10 per cent of time. Also fresh H_2O_2 and NH_4OH were added each day for 4 days. Then the solutions were decanted and the residues washed three times with distilled water by decantation. Also after filtration they were washed again three times on the filter paper. They were then dried at 50°C.

A number of tests were made for volatile ammonium salts in the residues by heating the treated samples to a temperature of 300°C. for periods varying between 10 to 30 minutes. No appreciable losses could be detected. Three grades of hydrogen peroxide were used. Two of them contained ammonium salts to start with. These did not interfere appreciably. All the experiments of Table 1 were carried out with the purest H_2O_2 obtainable, Merck's "Regent Superoxol," which contained less than 0.001% of "nitrogen compounds as N."

The dried samples were *x*-rayed by the powder method. Unfiltered iron radiation and precision cameras with a radius of 57.3 mm. were used. Though the diagrams are very satisfactory, no attempt is made to reproduce them here as too much detail would be lost in printing the films. It must be pointed out that much similarity exists between certain lines of the powder-diagrams of vermiculites and members of the chlorite group. It is, therefore, possible for appreciable amounts of chlorite to be concealed in vermiculite, especially if interstratification is in almost molecular layers. Some vermiculite lines are very similar to biotite lines, and in the alteration of the mineral to biotite, they might lead to doubtful interpretations. Fortunately the basal reflections of the two minerals are so different that no confusion is possible. Besides, the basal reflections due to the treatment received by the mineral are broader than all the other lines and can be distinguished with ease. In every case, a comparison of the film of the treated material with a film of typical biotite (Mora biotite, Mora, Minnesota[6]), shows their similarity at a glance. Except for the fact that the spacings of the basal planes are slightly greater in the synthetic micas, the structures are unquestionably very similar.

Most of the films show that considerable amounts of the original material are still vermiculite (or possibly chlorite since the two cannot be distinguished when present in small amounts). The lines of the unaltered residue are always sharper than the new ones.

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[6] See for example, Gruner, J. W., *Am. Mineral.*, **20**, 701 (1935).

One experiment was made at a temperature of 300°C. in a gold-lined bomb of 50 cc. capacity. Powdered vermiculite #1 (0.2 gram), 1 gram $(NH_4)_2CO_3$,[7] and 25 cc. distilled water were put into the bomb, and the space above the solution was filled with CO_2. After four days the results (Table 1) were about the same as in the other experiments conducted at room temperature. Substitution of a concentration of 1:1 ammonium hydroxide instead of a few drops in some experiments produced very similar results. The mineral samples absorbed somewhat less NH_4 under these conditions. Hydrogen peroxide alone exfoliated the vermiculites but did not change their powder diagrams. Blank tests for NH_4 made on the original minerals gave negative results.

Experiments in which hydroxides and salts of potassium and sodium were substituted for NH_4OH did not yield results which were uniform, and in most of these cases mica could not be identified. There were some changes and shifting of lines, but they could not be interpreted with certainty. Mica was produced, however, from vermiculite in a bomb experiment at 300°C. by introducing K ions from a KCl solution, but as this experiment was made in connection with a different problem, it will be reported in another place. Experiments with rubidium and caesium salts are under way at present.

CHEMICAL CONSIDERATIONS

The structural formula of vermiculite is $(OH)_2(Mg,Fe)_3(Al,Si)_4O_{10}\cdot 4H_2O$ as described previously.[8] To become a mica the H_2O molecules between the mica-like layers must be expelled and alkali or NH_4 ions must fill positions between the layers. In this transfer the structure should shrink from about 14 Å thickness per layer to about 10 Å. (A unit cell is two layers high.) It is obvious that the speed and completeness of this reaction depends upon the ease with which the H_2O molecules can leave and the NH_4 ions can enter. This depends largely on the thoroughness with which the hydrogen peroxide can exfoliate the vermiculite. That this exfoliation does not proceed to molecular layer size is evident, among other things from the fact that one still obtains fair powder diagrams.

On the other hand, some specimens, for example, proto-vermiculite, from Magnet Cove, Ark., and nickeliferous vermiculite from Webster, N. C.,[9] exfoliate very little. Neither do they react with NH_4OH to form mica. Another important factor is the "purity" of the material. If 10 to 20 or more per cent of the biotite layers are interlayered with brucite layers, in other words, are really chlorite in structure, no H_2O molecules are removed nor NH_4 ions introduced in these layers.

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[7] "Baker's analyzed" reagent.

[8] Gruner, J. W., *op. cit.*, p. 574.

[9] See specimens No. 2 and No. 7 respectively. Gruner, J. W., *op. cit.*, p. 558.

Since the NH_4 group is about the size of the K ion (probably slightly larger) the NH_4 mica layer theoretically should be only 10.0 Å thick. If statistically every tenth layer were a chlorite layer the powder diagrams should look about the way they do. In the original vermiculite this chlorite would remain entirely undetected because its unit cell has almost identical dimensions. If every possible alkali position in mica of the composition of Table 1 (disregarding H_2O) were occupied by an NH_4 group, the mica would contain about 4 per cent NH_4. Only about half of the positions seem to be filled according to analyses of row G, Table 1. This discrepancy cannot be explained by the presence of chlorite alone or by only partial alteration, though together they might account for it.

It is noteworthy that the apparent losses of H_2O (Row K, Table 1) are of the same order as the gains in NH_4, as might be expected. The small losses of H_2O (Row H, Table 1) below 300°C. are even more significant. They show that H_2O was removed in considerable amounts from positions in which it was held loosely. Though it is difficult to determine the optical constants on the altered materials, there is a consistent increase in the indices of refraction, noticeable as shown in L and M, Table 1.

A point little understood in this investigation is how charged NH_4 groups can enter between the layers which apparently are neutral. That the groups are charged must be assumed because they are held with great tenacity between the layers. Heating at 300°C. for 48 hours will not expel them (Row E, Table 1). At 650°C. the structure will collapse, however, to talc (Row F) as shown by the spacing of the layers. It is not possible to analyze for ammonia by simply heating the samples in a tube furnace and collecting the gases. Evidently the NH_3 is decomposed under these conditions. The analyses for NH_3 were carried out as described below.[10]

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[10] The weighed sample (25 to 50 milligrams) was decomposed by heating in a platinum crucible with a small amount of an HCl-HF mixture. The resulting solution was transferred to a 150 cc. flask, and treated with an excess of NaOH. After distillation, the ammonia content of the distillate was determined in the usual manner, by using Nessler's Reagent, and making colorimetric comparison with standard ammonium chloride solution. Blank determinations were made to correct for any ammonium salts in the reagents used. The decomposition of the sample by HCl-HF mixture may be omitted as equally satisfactory results were obtained by direct treatment with NaOH solution.

There is the possibility that charges exist between the layers of vermiculite, perhaps in the form of hydronium (H_3O) groups. Such an assumption would not necessarily oppose the idea of *two* layers of H_2O molecules between the sheets, as strongly advocated by Hendricks and Jefferson.[11] The following two arguments would be in favor of charges between the layers:

(1). Driving out of half the H_2O does not seem to affect the structure, as may be seen in the powder diagrams.

(2). The spacing of the layers is uniform for all true vermiculites and it has not been possible so far to produce a structure intermediate in spacing between the mineral proper and pyrophyllite to which it collapses when all H_2O is driven out.

In other words, it has not the properties of contraction or expansion which make montmorillonite and nontronite so unique, in spite of apparent great similarity of their layers otherwise.

Conclusions

Experiments show that NH_4 can enter the structure of vermiculite in such a manner that the mineral becomes an ammonium mica. The replacement of H_2O layers by NH_4 layers is not complete due to the difficulty of access of NH_4 groups between all the layers. Also the probable presence of chlorite units in appreciable amounts between vermiculite units causes apparently incomplete substitution. The introduction of ions of the alkalies Na and K does not seem to produce micas under similar conditions. More work is needed on this phase of the investigation. How charged NH_4 groups can enter apparently neutral layers of vermiculite is not understood. It is suggested that there may exist charges between the layers of vermiculite, possibly in the form of H_3O groups which can be replaced by NH_4 groups.

[11] Hendricks, S. B., and Jefferson, M. E., *Am. Mineral.*, **23**, 863–875 (1938).

A TORSION MICROBALANCE FOR THE DETERMINATION OF SPECIFIC GRAVITIES OF MINERALS

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Introduction

The specific gravity of a substance, especially a crystalline substance, is one of its fundamental properties. Since x-ray crystal studies have appeared, the property has become of considerable importance because the volumetric relations of the x-ray cell and the composition are tied together by the specific gravity.[1]

Specific gravities of minerals have been useful in determinative schemes, but the property has not been used extensively because: (1) there is a certain amount of variation in composition within the mineral species, (2) the existing data are not too reliable, (3) reliable values could only be obtained under exceptional circumstances, or with an expenditure of considerable time.

A satisfactory and practical method for measurement of specific gravity must provide:

1. Homogeneity of sample.
2. Simplicity and rapidity of measurement.
3. Significant accuracy.
4. Large range of application.

The writer believes that the new microbalance now in use in the Harvard mineralogical laboratory meets the requirements of a satisfactory method and, because the balance can give satisfactory results with small samples, it is especially useful to mineralogists.

Methods in General Use

The ordinary methods for the determination of specific gravity of solids are: (1) pycnometer methods, (2) suspension methods, (3) hydrostatic methods.

Pycnometer methods. The principal advantage of the pycnometer method lies in its use of powdered material. Under favorable circumstances, i.e., homogeneity and abundance of sample, no other method can yield such accuracy. The chief disadvantage of the method lies in the excessive care necessary and consequent time required to secure reliable results.

Recently Bannister and Hey (1938) and Winchell (1938) have described micropycnometer methods. As little as 5 mg. of solid can be used, according to Bannister and Hey, with a computed accuracy of about 0.5 per cent, using a microbalance for weighings. Winchell used about 100 mg. of material with a comparable accuracy, using an ordinary balance.[2]

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[1] $W=dVA$, where W = molecular weight of unit cell, V = volume of the unit, A = Avogadro number, d = specific gravity.

The Bannister and Hey method is apparently of some complexity, since it involves either a centrifuge process or special evacuation methods to free residual air bubbles without ejection of the solid. The Winchell method cannot conveniently handle less than the specified amount of material (100 mg.). The least time required for a determination (after considerable experience and using a previously calibrated pycnometer) is about an hour.

Suspension methods. The so-called suspension method has as its only serious limitation the restricted range over which suitable liquids are available. Clerici solution and a number of other heavy liquids[3] are suitable, but such minerals as the sulphides and oxides fall out of the range of the liquids. The liquids of highest specific gravity sometimes react with the sample and thereby further restrict the usefulness of the method.

Minerals of high specific gravity can be brought into the range of the liquids by attaching a glass float of known weight and density to the mineral sample. The combined mineral and float are then measured, and the specific gravity of the mineral can be readily computed. The accuracy obtainable is about that of the micropycnometer methods, i.e., about half a per cent.

In general, a good determination with the suspension method requires about an hour, or perhaps somewhat less, under favorable conditions.

Hydrostatic methods. The method of hydrostatic weighing is the simplest of the three principal methods here discussed. Only two weighings are necessary, in air and in the liquid. The only limitations to accuracy are weighing difficulties and surface tension effects. The former may be

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[2] The evaluation of errors, in the pycnometer method, due to weighing and temperature uncertainties, is given by the expression (Winchell, *Am. Mineral*, **23**, 805–810, 1938):

$$\frac{dS}{S} < \frac{dW_1}{W_2-W_1} + \frac{dW_2+dW_3}{W_2+sv-W_3} + \frac{(W_2-W_1)ds}{(W_2+sv-W_3)s}$$

where

S = specific gravity of powder
s = specific gravity of the liquid used
W_1 = weight of pycnometer empty
W_2 = weight of pycnometer with powder
W_3 = weight of pycnometer with powder and liquid
v = volume of pycnometer.

[3] See Rosenbusch-Wülfing, *Microskopische Physiographie*, v. **1**, pt. 1, 678, Stuttgart, 1921–24, for a general description of various liquids.

overcome by using a microbalance for small samples, and the latter by utilizing a liquid of low surface tension together with a suitably designed set of pans for weighing both in and out of the liquid.

The crudest of hydrostatic weighing devices can yield fairly good results on large enough samples, and is therefore suitable for the determination of the specific gravity of rocks. Many minerals are, however, unattainable in homogeneous fragments larger than 20 to 50 mgs. Experience in this laboratory has shown that reliable samples greater than 50 mgs. are rare.

The Jolly balance can conveniently handle a sample from 1 to 45 gms. and yield an accuracy of about 0.2 per cent with a 1 gm. sample of specific gravity 5.[4]

A microbalance with a sensitivity of 0.01 mg. handling 25 mg. of material, where the density of the liquid is correctly known to 0.001 and the sample has a specific gravity of 5, will yield an accuracy of about 0.2 per cent. This does not take into consideration a surface tension effect, but experience with such a balance in the Harvard laboratory has shown that this effect can be minimized by using a suitable pan and liquid, as described below.

THE TORSION MICROBALANCE

Description. The instrument shown in Fig. 1 is a modification of the Roller-Smith type "C" microbalance.[5] The range chosen for specific gravity measurements is to 25 mgs., with a vernier scale reading to 0.01 mg. The specified accuracy is 0.01 mg. The range of the balance may conveniently be increased to about 75 mg. by hanging suitable counterweights on the arm (*A* of Fig. 1). At *B* is hung a double weighing pan, made of .005″ platinum wire, coiled to make a basket at the bottom (Fig. 2) and holding an aluminum pan in its middle. The total weight is around 15 mg., and a tare hung at *A* is used. For weighing many small fragments together a basket is provided (Fig. 3). This is made of

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[4] In the equation for hydrostatic weighing methods

$$S=\frac{WD}{W-W_1}$$

where S = specific gravity of mineral, W = weight of mineral in air and W_1 = weight of mineral in liquid of density D, the limitations of accuracy due to weighing and liquid density effects may be expressed approximately as follows:

$$dS=\frac{WdD+DdW}{W-W_1}.$$

[5] Made by the Roller-Smith Company, Bethlehem, Pennsylvania, and distributed by Baird Associates, Cambridge, Mass.

220-mesh screening and weighs about 10 mg. The basket is hung on the top and bottom hook successively for weighings in and out of the liquid. The liquid is held in a glass dish which may be lowered and elevated by the knob, *C*, in order to facilitate loading the bottom pan. A conveniently located knob (*D*) enables the operator to adjust to a proper zero point (*E*) of the scale. At *F* a release (not seen in the figure) for the balance beam is provided.

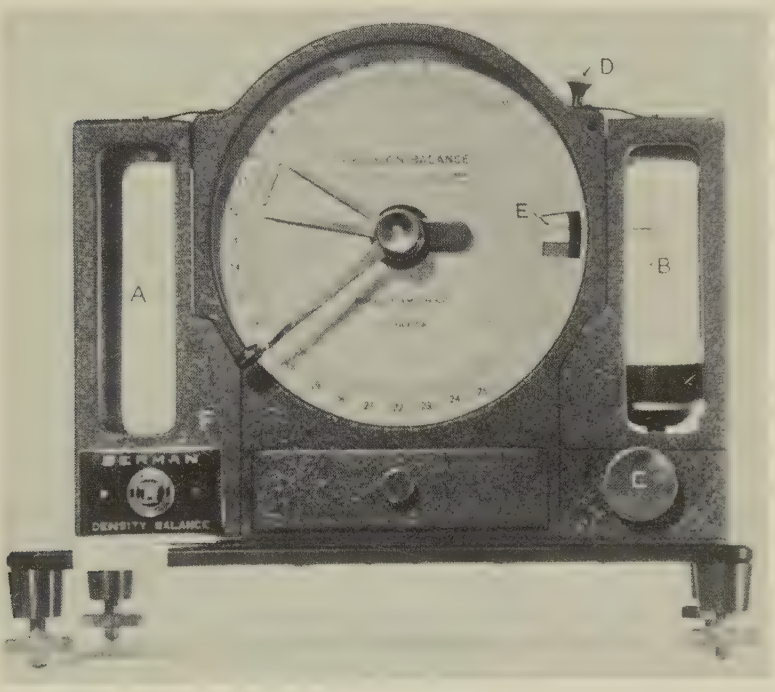
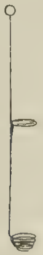


Fig. 1. Torsion Microbalance.



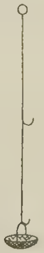


Fig. 2. Double weighing pan for single fragments.
Fig. 3. Basket and wire hook for coarse powder weighings.

After considering possible mechanical devices for loading single specimens on the upper and lower pans, all were rejected in favor of a small chute and a needle. The specimen is rolled from the chute (made of a folded piece of paper) onto the upper pan for the first weighing, and is pushed back on the chute with a needle after the weighing. On lowering the vessel carrying the liquid, the specimen is again rolled into the lower basket. From the latter the specimen cannot easily be pushed out but the weighings are completed, and the whole pan may then be lifted from the beam and inverted to expel the specimen.

A mark scratched on the vessel containing the liquid can be brought to the same place with respect to the pans for every reading. This cancels surface tension effects, and the weight of the immersed wire.

Toluene has been adopted as the displacement liquid for several reasons, most important of which is its low surface tension (29 ± .01; water = 73). The temperature coefficient[6] is such that little effect in the specific gravity can take place over the time of the experiment. Toluene of high grade may easily be obtained, and variations in specific gravities of different batches are small in terms of the accuracy obtainable with the balance. Carbon tetrachloride has also been found to be satisfactory.[7]

Advantages of the method. The method here described has as its chief advantages the following: (1) a small sample may be used; (2) a fair degree of accuracy is attainable; (3) the technique is simple and rapid; (4) it can be applied over the whole range of specific gravities of solids.

The use of a small sample is a great advantage because few minerals are homogeneous in bulk. Further, when single crystals are used for crystallographic, optical and x-ray work, the specific gravity of the same crystal can be determined. If a number of crystals are available, the method is still of advantage since a dozen measurements on separate samples can be made in the time usually given to making one measurement by other methods, and the averaged accuracy is high.

As before stated, the obtainable accuracy is 0.2 per cent with a 25 mg. specimen of specific gravity 5. Using a large number of fragments of total weight of 25 mg., specific gravity 5, and weighing in a basket, the accuracy is reduced to about 1 per cent. A complete determination takes about five minutes, and the technique is so simple that a student without experience can get good results at the first attempt. The instrument itself is rugged and apparently is not easily thrown out of adjustment.

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[6] The following expresses the variation of toluene with temperature: $d_t=d_s+10^{-3}\alpha(t-t_s)+10^{-6}\beta(t-t_s)^2$ where $d_s=0.8845$, $\alpha=-0.9159$, $\beta=+0.368$, $t_s=0°\text{C}$. From International Critical Tables, **3,** 29 (1928).

[7] For carbon tetrachloride, $d_s=1.63255$, $\alpha=-1.9110$, $\beta=-0.690$.

Examples and new data. In the following table are listed a portion of the routine measurements made in the Harvard laboratory. Where the calculated value from *x*-ray measurements is known, that value is given by way of comparison. Some of the listed minerals have been first measured, with some degree of accuracy, by this method. Most of the minerals, with the exception of the test samples, were measured in order to improve existing data which appeared imperfect as given in the literature.

Mineral	*Measured*	*Calculated (X-ray)*	*Per cent of error*	*Wgt. of sample in mg.*	*Remarks*
Albite	2.59			20	Ontario. Nearly pure. Coarse powder.
Antlerite	3.88 ± .005	3.93	1.29	31-6	
Baumhauerite	5.24			6	
Brochantite	3.97 ± .01	3.98	0.25	15-20	4 determinations.
Calcite	2.72	2.73	0.47	24	
Cobaltite	6.33	6.30	0.48	25	
Colusite	4.50	4.43	1.58	10	
Diamond	3.52	3.511	0.40	8	
Dyscrasite	9.82	9.85		70	Andreasberg.
Galena	7.58 ± .01	7.57	0.13	33–19	2 determinations.
Glaucodot	6.16 ± .02			4.56	Hakensbö, Sweden.
Gratonite	6.24 ± .01	6.17	1.12	14-8	2 determinations. Type.
Hopeite	3.04	3.08	1.32	12	Pycnometer measurement on 1.035 gms. gave 3.04 (Spencer).
Kallilite	6.66				
Kermesite	4.68	4.69	0.21	8	
Kröhnkite	2.90 ± .02	2.95	1.70	14-10-9	3 determinations.
Loellingite	7.40				3 determinations (29.40% Fe).
Loellingite	7.48				4 determinations (27.89% Fe).
Magnetite	5.00			29	Coarse powder.
Marshite					
Muscovite	2.84			13	Ontario. Coarse powder.
Nagyagite	7.40			15	
Natrochalcite	3.49 ± .01	3.54	1.43	20	3.476 from 2½ gms. by pycnometer.
Nepheline	2.62			18	Ontario. Coarse powder.
Pearceite	6.10			24	
Penroseite	7.05 ± .05			38-34-68	Hey's average 6.86.
Pyrostilpnite	5.94			5	
Quartz	2.65			21	Coarse powder.

Mineral	*Measured*	*Calculated (X-ray)*	*Per cent of error*	*Wgt. of sample in mg.*	*Remarks*
Salesite	4.77 ± .05	4.89	2.51	9	3 grains weighed together. Type.
Sphalerite	4.10	4.083	0.42	20	Santander.
Ullmanite	6.65	6.79	2.06	20	4 determinations.
Wagnerite	3.153 ± .003	3.158	0.16	15-23	4 determinations.

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CALEDONITE

CHARLES PALACHE AND W. E. RICHMOND, *Harvard University, Cambridge, Mass.*

Caledonite is a basic sulphate of copper and lead, concerning which there has long been doubt both as to its composition and its symmetry. It was first described by Brooke (1820) as a sulphato-carbonate of orthorhombic crystallization. The carbonate constituent was later thought to be derived from admixed cerussite, and Dana (1892) made it a sulphate. But the last published analysis of it by Berg (1901), discussed on a later page of this paper, seems to establish the correctness of the first determination. Although we have made no new analysis, we were able to make certain that crystals of the mineral dissolve with vigorous effervescence in nitric acid, depositing lead sulphate.

Schrauf (1871) first cast doubt on the orthorhombic symmetry of caledonite. Schrauf, and after him Jeremejew (1882), interpreted minute differences of equivalent angles and slight re-entrant angles on faces in the vertical zone as indicating monoclinic symmetry more or less concealed by basal twinning. Neither they nor any later observers were able to detect any optical evidence which supported the assumed aggregate structure; still the doubt remained. We are indebted to Dr. Berman for a careful optical examination of selected crystals. The only ones at hand which showed the re-entrant angles on the front pinacoid as described by Schrauf were from the type locality, Leadhills, Scotland. Sections normal to the two pinacoids were prepared and studied for discontinuities such as twinning should produce. In one or two preparations a discontinuity could be seen but the evidence was not deemed adequate to prove twinning. It could be equally well explained as due to subparallelism, especially as so few of the sections examined showed even the slightest optical discontinuity. These results agree with the morphological and *x*-ray evidence in confirming the orthorhombic symmetry of caledonite. This conclusion is in agreement with all recent morphological studies. The evidence is excellently summarized in Hintze (1929).

Material for a renewed study of this mineral was found in an undescribed specimen from the Talisman Mine, Beaver Creek, Utah, No. 66912 of the Harvard Mineralogical Collection. It is a small hand specimen of rock intersected by numerous narrow open veinlets on whose walls are crystals of cerussite, linarite and caledonite. The crystals of the last-named mineral are of a clear blue-green color and of high lustre and perfection. They closely resemble, except as to brilliance, specimens from the type English and Scottish localities, Cumberland and Leadhills, which were included in the study.

The position chosen by Brooke and Miller (1852) for caledonite with the *a* axis in the direction of the usual elongation has been followed by most later observers. But Greg and Lettsom (1858) took the elongation of the crystals as the *c* axis following Haidinger and Mohs (1839); and Schrauf (1871), to conform to his monoclinic interpretation, took the elongation as *b*, the symmetry axis. The lattice determination of Mr. Richmond makes the position of Greg and Lettsom the conventional one but with a doubled *b* axis. We adopt this usage; the doubled *c* axis (position of Brooke-Miller) had already been used by Ungemach (1912).

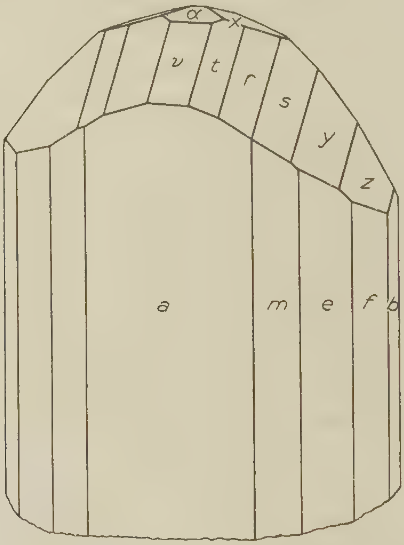

FIG. 1. Crystal of Caledonite from the Talisman Mine.

Goldschmidt in the Winkeltabellen (1897, p. 398) gives the elements of four observers and takes the mean as the best value to employ. Our measurements lead to values falling within the same range and we have therefore used Goldschmidt's elements and his angles, suitably transformed to the new position and unit form. Letters used for the forms follow Dana and Goldschmidt, except for the unit orthodome and the unit prism. Transformation formulas relating the various positions are as follows:—

Brooke and Miller to Palache 010/002/100
Greg and Lettsom to Palache 100/020/001
Schrauf to Palache 100/002/010

Table 1. Caledonite: Angle Table

Orthorhombic; dypyramidal—$2/m\ 2/m\ 2/m$

$a:b:c=0.3555:1:0.3263$; $p_0:q_0:r_0=0.9180:0.3263:1$

$q_1:r_1:p_1=0.3555:1.0893:1$; $r_2:p_2:q_2=3.0647:2.8134:1$

	ϕ	$\rho=C$	ϕ_1	$\rho_1=A$	ϕ_2	$\rho_2=B$	G & L	B & M	Sch.
b 010	0°00′	90°00′	90°00′	90°00′	—	0°00′	010	001	001
a 100	90 00	90 00	—	0 00	0°00′	90 00	100	010	100
h 1.32.0	5 01½	90 00	90 00	84 58½	0 00	5 01½	—	0.1.16	1.0.16
g 1.16.0	9 58½	90 00	90 00	80 01½	0 00	9 58½	—	018	108
k 1.12.0	13 11½	90 00	90 00	76 48½	0 00	13 11½	—	016	106
i 1.10.0	15 43	90 00	90 00	74 17	0 00	15 43	150	015	—
o 180	19 22½	90 00	90 00	70 37½	0 00	19 22½	—	014	—
ψ 160	25 07½	90 00	90 00	64 52½	0 00	25 07½	—	013	$\bar{1}03$
f 140	35 07	90 00	90 00	54 53	0 00	35 07	—	012	±102
κ 130	43 09½	90 00	90 00	46 50½	0 00	43 09½	—	023	—
e 120	54 35½	90 00	90 00	35 24½	0 00	54 35½	110	011	+101
m 110	70 26	90 00	90 00	29 34	0 00	70 26	—	021	$\bar{2}01$
x 011	0 00	18 04½	18 04½	90 00	90 00	71 55½	012	201	—
d 021	0 00	33 07½	33 07½	90 00	90 00	56 52½	—	101	—
α 102	90 00	24 39½	0 00	65 20½	65 20½	90 00	—	—	—
ν 101	90 00	42 33	0 00	47 27	47 27	90 00	101	110	110
β 201	90 00	61 25½	0 00	28 34½	28 34½	90 00	—	—	—
t 111	70 26	44 15	18 04½	48 53½	47 27	76 29	212	221	±221
r 121	54 35½	48 24	33 07½	52 27	47 27	64 19½	111	111	±111
s 131	43 09½	53 18½	44 23½	56 44	47 27	54 12	232	223	±223
y 141	35 07	57 55½	52 32½	60 49½	47 27	46 07½	—	—	—
z 151	29 22	61 53½	58 29½	64 22½	47 47	39 46	—	—	—
τ 161	25 07½	65 11	62 56½	67 20	47 27	34 44	—	113	—

Uncertain forms:
Schrauf {1.48.0}, {1.40.0}, {1.24.0}, {1.20.0}, {3.10.3}, {787}, {10.1.10}.
Other authors {241}, {201}, and {151}.

Four crystals of caledonite from the Talisman Mine were measured and yielded several new forms as well as most of the well-established forms previously recorded. The prism zone is, as in all described crystals, much striated. However, distinct faces of *f*, κ, *e*, and *m* were observed. The terminal faces are sharp and in exceptionally accurate position, as may be seen from the following summary of measured angles on the crystal reproduced in the figure with but slight idealization.

TABLE 2. CALEDONITE: MEASURED ANGLES ON THE TERMINATION OF ONE CRYSTAL

	Mean		Range		No. of faces
	ϕ	ρ	ϕ	ρ	
011	0°03′	18°10′	0°17′– 0°24′	—	2
*102	90 10	24 33½	90 02 –90 19	24°30′–24°17′	2
101	90 06	42 33½	90 02 –90 10	42 26 –42 41	2
*201	90 00	61 28	—	—	1
111	70 26	44 17	70 22 –70 35	44 08 –44 25	4
121	54 30	48 30	—	48 22 –48 38	2
131	43 10	53 22½	43 03 –43 18	53 14 –53 32	4
*141	35 07½	58 02	35 06 –35 09	57 57 –58 07	2
*151	29 18	62 05	—	—	1
161	25 10	65 13	25 07 –25 14	65 12 –65 15	2

* New forms.

The forms (102) and (141) were found on two other crystals and are well established. The forms (201) and (151) since each was seen but once, may be held in some doubt, although the position of each was excellent. The latter took the place of a face of (161) in the quoin of the crystal where it occurred.

Optical properties. The optical data on caledonite have been revised by Dr. Berman. In the new orientation, they are:—

$X = c^* = 1.818$
$Y = a = 1.866$
$Z = b = 1.909$

Biaxial negative
$2V = 85° \pm$
$r < v$ slight

X-RAY EXAMINATION OF CALEDONITE

BY W. E. RICHMOND

The crystal fragment used for the x-ray study was a cleavage fragment separated from a larger crystal which showed macroscopically some evidence of aggregate structure. Special care was taken to select a fragment consisting of a single individual. The crystal was mounted so as to rotate about an axis normal to the perfect cleavage {010}, since this direction was the symmetry axis of the monoclinic interpretation of Schrauf. X-ray rotation photographs and zero, first and second layer-line Weissenberg photographs were taken about this axis. The first and second layer-line photographs revealed no evidence of monoclinic symmetry; they thus compel the conclusion that the mineral is orthorhombic as indicated by morphological study.

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*Indices from Larsen's tables. The orientation there given $X = b$, which follows Dana, doubtless came from Descloizeaux. The latter gives $X = a$, which is correctly quoted by Hintze. Dana is in error as is Larsen. Dr. Berman checked the orientation, as given above, on crystals from Utah and Leadhills.

The lattice constants derived from the photographs are:—

$a_0 = 7.14\text{Å}$ $a_0{:}b_0{:}c_0 = 0.356{:}1{:}0.326^5$
$b_0 = 20.06\text{Å}$ $a{.}b{:}c = 0.3555{:}1{:}0.3263$ (morphology)
$c_0 = 6.55\text{Å}$ $V_0 = 938.3$ cub. Å

The space group is $D_{2h}^{13}-P_{nmm}$ determined by the reflections:

(*hkl*) all present
(0*kl*) with $k+l$ even
(*h*0*l*) all present
(*hk*0) all present

Content of the unit cell. A new value for the specific gravity was determined on single crystals with the micro-torsion balance, $G = 5.76 \pm .01$. The analysis chosen for discussion was that published by Berg (1901), since his description of the preparation of the analysis sample indicates that special care was used to avoid contamination by cerussite. The following table exhibits the results obtained using V_0 and G as stated above.

Table 3. Composition of Caledonite

	1	2		3	4	5
CuO	9.73	0.122	Cu	0.122	4.00	4
PbO	69.18	0.310	Pb	0.310	10.13	10
CO_2	3.16	0.072	C	0.072	2.36	2
SO_3	14.15	0.177	S	0.177	5.80	6
H_2O	3.78	0.209	H	0.418	13.67	12
			O	1.316	43.10	42
	100.00					

1. Analysis of caledonite from Challocolla, Chile, recalculated to 100 per cent. Analyst Liebert in Berg (1901).
2. Molecular proportions.
3. Atomic proportions.
4. Number of atoms in the unit cell.
5. Assumed theoretical number of atoms in unit cell.

The cell formula is therefore

$$2[Cu_2Pb_5(SO_4)_3(CO_3)(OH)_6].$$

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RHYODACITE FROM THE TRANQUILLE PLATEAU, BRITISH COLUMBIA*

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Siliceous lavas are very uncommon in the Tertiary volcanics of the British Columbia interior plateaus, and the present paper records what is believed to be the first such occurrence to be studied in petrographic detail. The rhyodacite here described was found in the unpopulated upper Tranquille plateau area about 25 miles northwest of Kamloops, on the old wagon road from Tranquille to Red Lakes and Copper Creek. The outcrop is an elliptically shaped area 300 feet wide and 500 feet long. Flat-lying basalt flows surrounding it give a steptoe appearance suggesting a volcanic plug.

Apparently this is the rock that Dawson lists in his Tertiary volcanic groups as "dacite, Upper Tranquille Valley."[1] Dawson assigned his "Upper Volcanic Group" to the Miocene. Later Drysdale[2] reached a similar conclusion, but Daly[3] believed that the group was of Oligocene age. The decision seems to rest on paleontological evidence but, in any case, it seems agreed that these are middle-Tertiary lavas.

The rock is white, fine-grained, and porphyritic. The outcrop is homogeneous, and thin sections from many parts of the outcrop show no significant differences. Phenocrysts of oligoclase, sanidine, quartz and biotite are embedded in a microcrystalline groundmass (Fig. 1). The composition corresponds to 237E of Johannsen's classification, a rhyodacite.[4] Eighty-six per cent of the rock is groundmass.

Plagioclase, constituting 6 per cent of the rock, is the most abundant phenocryst. It occurs as unzoned subhedra, with the usual multiple twinning. All of the plagioclase is oligoclase, Ab 78 An 22, and the few grains occurring in coarser phases of the groundmass have similar composition. The indices of refraction of the oligoclase are: $\alpha=1.541$, $\beta=1.545$, and $\gamma=1.548$. The absence of zoning is probably explained by slow early crystallization with complete reaction and equilibrium.

Sanidine variety of orthoclase, making up 4 per cent of the rock, is a conspicuous feature (Fig. 2). Twinning is present, but untwinned euhedra and subhedra are more common. The sanidine has the following indices of refraction: $\alpha = 1.522$, $\beta = 1.526$, and $\gamma = 1.527$.

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* Presented December 29, 1938, at the annual meeting of the Mineralogical Society of America held in New York, N.Y.

[1] Dawson, George M., Report on the area of the Kamloops Map-Sheet, British Columbia: *Canadian Geol. Survey, Ann. Rept.*, **226B** (1894).

[2] Drysdale, Charles W., Transcontinental Excursion C1, Part II, Toronto to Victoria and return: *Canadian Geol. Survey, Guide Book* No. **8**, 243 (1913).

[3] Daly, R. A., Transcontinental Excursion C1, Part II, Toronto to Victoria and return: *Canadian Geol. Survey, Guide Book* No. **8**, 233 (1913).

[4] Johannsen, Albert, *A Descriptive Petrography of the Igneous Rocks*, **2**, 356–358 (1932).

Quartz phenocrysts make up 3 per cent of the total. They are mostly corroded, egg-shaped anhedra, suggesting partial solution by a magma which was silica-poor during its later stages. Neither tridymite nor cristobalite could be discerned by ordinary microscopic methods. Slightly coarser-grained sections of the groundmass, where tridymite might be expected,[5] are seen to contain only quartz. However, the groundmass contains irregular spherulites, and the recent *x*-ray work of Hurlburt and others suggests that cristobalite may occur here.[6]

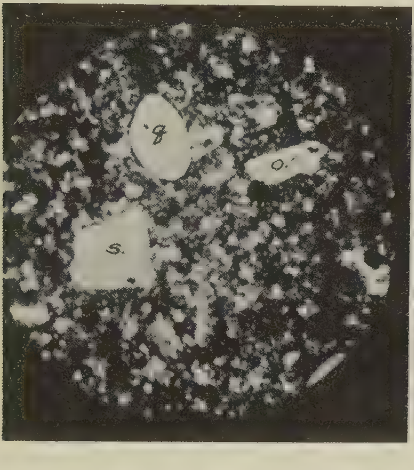

FIG. 1. Thin section showing the typical rock texture, with sanidine (s), quartz (q), and oligoclase (o) as phenocrysts. Crossed nicols. Enlarged 17 diameters.

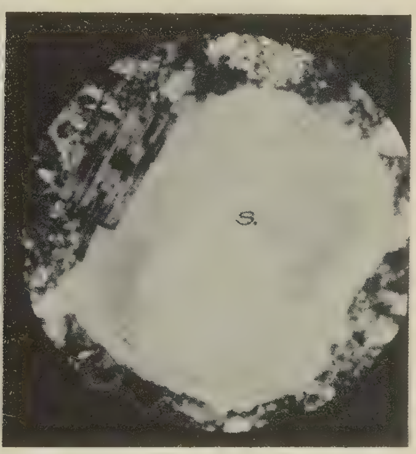

FIG. 2. Thin section showing sanidine (s). Biotite with magnetite is also prominent. Crossed nicols. Enlarged 48 diameters.

Nearly one per cent of the rock is brown biotite. No other mafics are present in the thin sections. The minor accessory minerals were studied by heavy mineral separations. Most of the heavy minerals proved to be magnetite, amounting to nearly one-half per cent of the total rock, but zircon, fluor-apatite, sphene, and common hornblende are also found.

The writer wishes to thank the following persons for helpful advice: Miss Elizabeth Ferguson, science librarian, and Professor George E. Goodspeed, University of Washington; Professor Esper S. Larsen, Harvard University; and Dr. John S. Stevenson, British Columbia Department of Mines.

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[5] Larsen, Esper S., and others, Petrologic results of a study of the minerals from the Tertiary volcanic rocks of the San Juan region, Colorado: *Am. Mineral.*, **21,** 693 (1936).

[6] Hurlburt, Cornelius S., Jr., *X*-ray determination of the silica minerals in submicroscopic intergrowths: *Am. Mineral.*, **21,** 727–730 (1936).

THE ROTATION FACTOR FOR EQUI-INCLINATION WEISSENBERG PHOTOGRAPHS

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In the analysis of crystal structures by means of x-rays it is well known that when the reflecting plane does not contain the axis of rotation of the crystal (in other words, when the diffraction spot does not lie on the equatorial line of the photograph), the angular velocity of the plane is effectively decreased. This results in reflection by such a plane during a longer interval of time in each rotation than by planes producing spots on the equatorial or zero layer-line. Cox and Shaw[1] have shown that the effect is purely geometrical, depending only on the angle of reflection and the orientation of the reflecting plane with respect to the axis of rotation of the crystal, and they have calculated the magnitude of this effect for rotation photographs taken with the x-ray beam perpendicular to the rotation axis of the crystal. In view of the fact that it is advantageous[2] to take Weissenberg layer-line photographs with the rotation axis of the crystal inclined to the incident x-ray beam at an angle equal to that made by the rotation axis with the reflected x-ray beams for the layer-line that is being analyzed, the author has derived the relationship for the rotation factor D_e appropriate under such conditions. As Cox and Shaw have stated, the intensity of the spot produced by a reflecting plane is inversely proportional to ω/Ω, where ω is the angular velocity of the crystal about an axis perpendicular to the plane containing the incident and reflected x-ray beams, and Ω is the angular velocity of the crystal about its actual rotation axis.

The value of D_e is obtained by the following construction, which is similar to that used by Cox and Shaw in deriving the value of the rotation factor in the case of an x-ray beam perpendicular to the rotation axis of the crystal. Figure 1 shows the geometrical relations of the crystal, incident x-ray beam, and reflected x-ray beam in stereographic projection. O is the point of emergence of the rotation axis of the crystal; this rotation axis passes through the center of the sphere of projection. The incident x-ray beam passes through A to the center of the sphere of projection. B is the pole of the reflecting plane. The reflected x-ray beam passes from the center of the sphere of projection to C. Let ϕ denote the angle AB, and μ denote the angle DA. The essential feature of the equi-inclination method is that for each layer-line the rotation axis of the crystal is set at an angle AO to the incident x-ray beam such that the reflected x-ray beam for each spot on the layer-line makes an angle OC with the rotation axis of the crystal equal to AO. Then, since the angle of incidence equals the angle of reflection, we have

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[1] *Proc. Roy. Soc. London*, **127A**, 71–88 (1930).

[2] Buerger, M. J., *Zeits. Krist.*, **88**, 356–380 (1934).

$$AB = BC,$$

and since

$$AO = OC = 90° - \mu,$$

therefore

$$OBC = OBA = 90°.$$

Let ν denote the angle AOB. The angular velocity of the crystal is $d\nu/dt$, where t denotes the time, and $d\nu/dt$ is a constant during the investigation of the crystal by the Weissenberg method. The angular velocity of the normal to the reflecting crystal plane about the normal to the plane ABC is $d\phi/dt$. Then

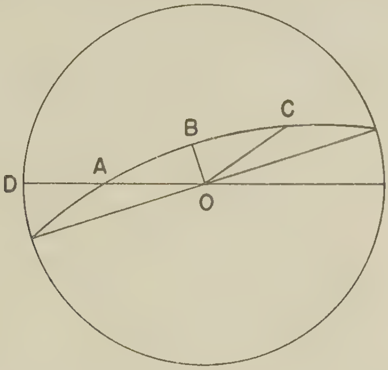

FIG. 1. Stereographic projection showing crystal rotation axis (passing through O and center of sphere), normal to crystal reflecting plane (pole of crystal reflecting plane is point B), incident x-ray beam (passing through A and center of sphere), and reflected x-ray beam (passing through center of sphere and C).

$$D_e = \frac{\omega}{\Omega} = \frac{\dfrac{d\phi}{dt}}{\dfrac{d\nu}{dt}} = \frac{d\phi}{d\nu}.$$

Since the spherical triangle OBC has a right angle at B, we have

$$\sin\phi = \sin\nu \cdot \sin(90° - \mu).$$

Thus

$$\frac{d\phi}{d\nu} = \frac{\cos\nu \cdot \cos\mu}{\cos\phi}.$$

But $\phi = 90° - \theta$, where θ is the angle made by the reflected beam with the reflecting crystal plane. Hence

$$D_e = \frac{d\phi}{d\nu} = \frac{\sqrt{\cos^2\mu - \cos^2\theta}}{\sin\,\theta}. \tag{A}$$

TABLE 1. DATA FOR PLOTTING CURVES OF CONSTANT D_e. VALUES OF $\mu°$ CORRESPONDING TO DIFFERENT VALUES OF SIN θ AND D_e.

$D_e \rightarrow$	.99	.975	.95	.925	.90	.85	.80	.70	.60	.50	.40	.30	.20	.10	.00
Sin θ ↓	$\mu°$														
0.1	0°.81	1°.28	1°.79	2°.18	2°.50	3°.02	3°.44	4°.10	4°.59	4°.97	5°.26	5°.47	5°.62	5°.71	5°.74
0.2	1.62	2.55	3.58	4.36	5.00	6.05	6.89	8.21	9.21	9.97	10.56	11.00	11.30	11.48	11.54
0.3	2.43	3.82	5.38	6.54	7.51	9.09	10.37	12.37	13.89	15.06	15.96	16.63	17.09	17.37	17.46
0.4	3.23	5.10	7.18	8.74	10.04	12.16	13.89	16.60	18.66	20.27	21.51	22.43	23.07	23.45	23.58
0.5	4.04	6.38	8.98	10.95	12.59	15.27	17.46	20.92	23.58	25.66	27.28	28.49	29.33	29.83	30.00
0.6	4.86	7.66	10.80	13.18	15.16	18.42	21.10	25.37	28.69	31.31	33.36	34.92	36.01	36.66	
0.7	5.67	8.95	12.62	15.42	17.77	21.64	24.84	29.99	34.06						
0.8	6.48	10.24	14.47	17.70	20.41	24.92	28.68	34.84							
0.9	7.29	11.54	16.32	20.00	23.10	28.30	32.68								
1.0	8.11	12.84	18.20	22.33	25.84	31.79									

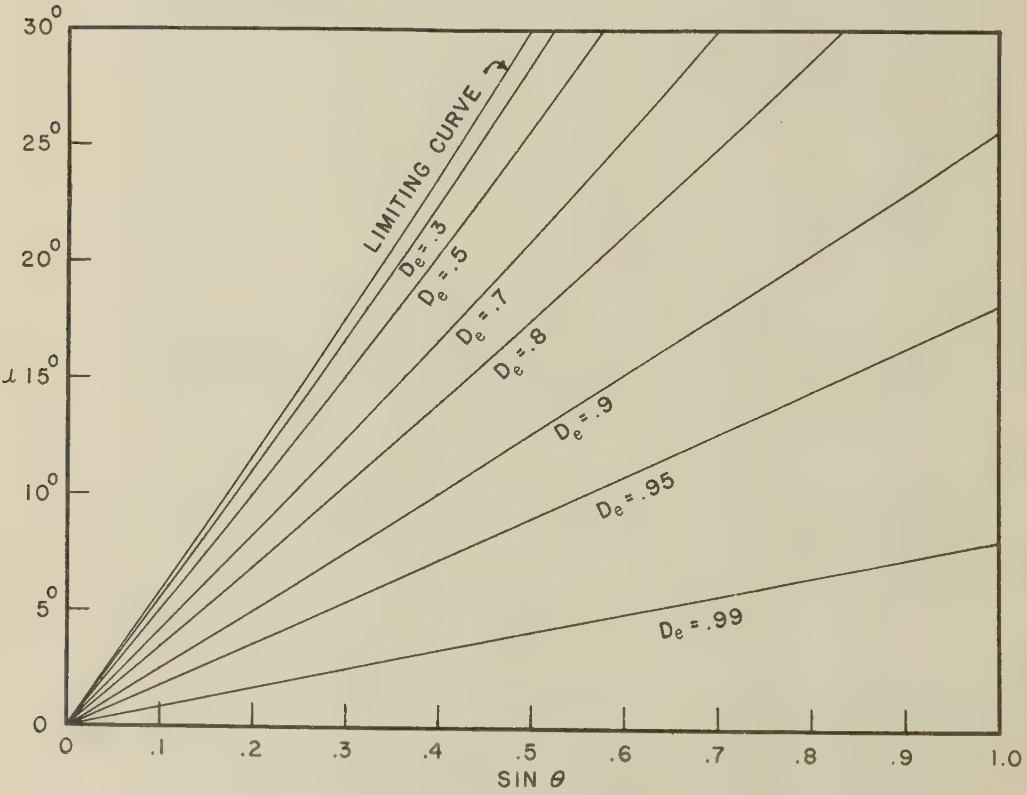

FIG. 2. Rotation factor D_e for equi-inclination Weissenberg photographs.

The variation of D_e with μ and $\sin\theta$ as arguments is shown graphically in Figure 2. Table 1 is intended for the convenience of users of the equi-inclination method in plotting the curves of constant D_e on a larger scale necessary for the graphical determination of the values of D_e corresponding to the reflections on the equi-inclination layer-line films. The value of the rotation factor for any given reflection will always be nearer one in the equi-inclination method than in the method of perpendicular incidence (the crystal being assumed to rotate around the same zone-axis in both cases). Moreover, it is to be noted that in the equi-inclination method the factor D_e approaches $\cos\mu$ for diffraction spots near the incident beam (back reflection), whereas in the method of perpendicular incidence it approaches zero for such spots on all layer-lines except the equator. This constitutes a further advantage of the equi-inclination method. The factor D_e is plotted for values of μ up to 30° only, but this is equivalent to a μ-value of 90° in the method of perpendicular incidence. A μ-value greater than 30° will seldom be required with the equi-inclination method. If such a case is encountered the necessary values of D_e can be computed from equation (A).

CHLORITE VEINS IN SERPENTINE NEAR KINGS RIVER, CALIFORNIA

Cordell Durrell and Gordon A. Macdonald,
University of California at Los Angeles and Shell Oil Co.

Introduction

In the vicinity of the Kings River, in the western foothills of the Sierra Nevada, California, there are several localities showing narrow veins of chlorite cutting serpentine. There are two such localities in the northwestern part of the Dinuba quadrangle. One locality is about 1¼ miles N 20° E of the top of Wildcat Mountain, in the eastern half of section 11, T. 12 S., R. 23 E. The other, which is better exposed and more easily accessible, is described in the present paper. It is exposed in road-cuts along the highway which follows the north side of the Kings River, about ⅜ mile southwest of the northern end of the bridge at Piedra.

Clinochlore zones in serpentine, which appear to be similar in nature to those described here, have also been recorded from Bernstein, Austria.[1]

General Geology

The crystalline "Bedrock Complex" of the Sierra Nevada is made up in this region of a series of metamorphosed sedimentary and volcanic rocks which have been intruded by the granitic rocks of the Sierra Nevada batholithic complex. At some time previous to the Nevadan (Late Jurassic) orogeny and batholithic invasions, there were intruded into the sedimentary and volcanic rocks sills of serpentine, some of them of very large size. These serpentine bodies have undergone the same degree of folding and metamorphism (both dynamothermal and contact) as the enclosing rocks.

Petrography

Serpentine: The serpentine in which the chlorite veins are found is a hard, brittle rock of dark to pale grayish-green color. Under the microscope it is seen to consist of tiny, irregular grains of olivine and a few scattered prisms of pale green actinolitic hornblende, set in a groundweb of reticulate plates of antigorite. A few crystals of magnetite and apatite are present. Scattered flakes and streaks of talc are common, and short, discontinuous veinlets of a carbonate, probably magnesite, occur. Net structure, such as is commonly observed in unmetamorphosed serpentines, is completely lacking.

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[1] Smith, W. C., On a compact chlorite from Bernstein, Austria: *Mineral. Mag.*, **20**, 241–244 (1924).

Within 5 to 30 mm. from the chlorite veins the serpentine becomes enriched in amphibole and clinochlore, and passes into an actinolite-clinochlore rock containing a small amount of talc. This zone terminates with great suddenness, and usually at a slickensided surface, against the chlorite veins. A few tiny veinlets of chlorite are found within this zone, but they are invariably composed entirely of clinochlore.

Megascopic features of the chlorite veins: The chlorite veins are found at intervals of from one to several feet, cutting the serpentine in nearly vertical and parallel planes. They are locally bent as though folded, and they are almost invariably slickensided along one or both walls.

In thickness the veins range from less than an inch to six or even eight inches, but they reach this latter dimension only in local swellings. These swellings are lenticular, pod-shaped enlargements along continuous veins. Most of the veins are between one and two inches in thickness. Where they are of this order of magnitude, they are composed of large, hexagonal plates of clinochlore from one to four millimeters in diameter and from one to two millimeters in thickness, with finer grained chlorite between them. The greater part of these narrow veins is clinochlore. The fine grained interstial material consists of positive and negative penninite and an unnamed chlorite.

In some places plates of clinochlore are concentrated along the edges of the veins, with the basal planes nearly normal to the walls, but in all azimuths. Locally, in the central parts of the veins, the plates of clinochlore do not touch each other, and they then show a quite complete development of crystal faces.

In the larger swellings the chlorites are often arranged in the same manner, but a more perfect banding is frequently exhibited. In the latter case the clinochlore is concentrated at the edges of the veins, which consist of nearly pure clinochlore for a thickness of from 5 to 25 mm. The central parts of the veins are here composed of finer grained aggregates of the other chlorites, in some instances with a few large idiomorphic plates of clinochlore.

Microscopic features of the chlorite veins: Under the microscope four varieties of chlorite are easily distinguished. Exact properties are, however, difficult to determine for the finer grained material. The indices of refraction were determined in oils, and are subject to a possible error of $\pm .002$.

The clinochlore shows abundant lamellar twinning parallel to $\{001\}$, repeated many times on each crystal. Its optical properties are as follows:

(+) $2V=5°\text{–}20°$ (average 15°)
(−) elongation
dispersion $r<v$, weak

X and Y = pale green
Z = colorless to very pale green
$\alpha = 1.581$
$\beta = 1.583$
$\gamma = 1.588$
$\gamma - \alpha = 0.007$

These properties fall within the range determined by Durrell[2] for clinochlore from the Rocky Hill district, about 40 miles to the south. A specimen of the latter has the composition shown below.

SiO_2	31.04%
Al_2O_3	18.77
Fe_2O_3	0.47
FeO	3.56
MgO	34.24
CaO	nil
H_2O (+)	10.40
H_2O (−)	1.10
Total	99.58

W. H. Herdsman, *analyst.*

The greater part of the fine grained aggregates of chlorite consists of penninite. Of the penninite, a variety which is optically negative and shows ultra-blue colors under crossed nicols is most abundant. A variety which is optically positive and shows ultra-brown colors is far less abundant, and occurs only as cores in crystals whose borders consist of the negative variety. The optical properties of these two varieties of penninite are as follows:

POSITIVE PENNINITE	NEGATIVE PENNINITE
(+) 2V = 30°–40°	(−) 2V = 0°
dispersion $r < v$, strong	
X and Y = very pale green	X = colorless
Z = colorless	Y and Z = very pale green
$\alpha = 1.578$	$\alpha = 1.574-$
$\gamma = 1.580$	β and $\gamma = 1.576+$
$\gamma - \alpha = 0.002$	$\gamma - \alpha = 0.002 - 0.004$
Characteristically shows strong ultra-brown interference color.	Characteristically shows strong ultra-blue interference color.

In addition to its occurrence in the fine grained aggregates, negative penninite is frequently found as rims on the large plates of clinochlore. The passage from clinochlore to penninite appears to be gradational.

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[2] Durrell, C., Metamorphism in the southwestern Sierra Nevada northeast of Visalia, Calif.: *Univ. Calif. Publ., Bull. Dept. Geol. Sci.*, in press.

A chlorite, the properties of which do not correspond to those of any described variety, is also abundantly represented in the veins. It occurs in the fine grained aggregates, either with positive and negative penninite, or as the sole constituent. It is also found interlaminated with clinochlore, the plates reaching a diameter equal to that of the large clinochlore crystals. Its properties are as follows:

(−) $2V=0°$
X = colorless
Y and Z = green, variable; usually pale, but in small areas very dark green
$\alpha=1.545$
β and $\gamma=1.565$
$\gamma-\alpha=0.020-0.022$

The indices of refraction of this mineral are low for chlorites, and the double refraction unusually high. However, chlorites with still higher double refraction have been described. Its properties are close to those of bowlingite, beidellite, and griffithite. All of these are hydrous and aluminous, and it seems very probable that the mineral here described is also aluminous.

Magnetite occurs throughout the veins in small, irregular crystals, and a few irregular grains of apatite are also present.

Chemical Constitution of the Veins

The essential feature to be noted is the alumina content of the vein materials. The alumina content of penninite is stated by Orcel[3] to range from 11.6 to 13.8 per cent, while that of the clinochlore is close to 18 per cent. The unnamed chlorite is almost certainly aluminous, although without additional information it is not possible to make any reliable estimate of its Al_2O_3 content. Even where this unnamed chlorite is present in considerable abundance, however, it seems safe to assume an Al_2O_3 content for the veins of at least 12 per cent, and in many of the veins, where this mineral is not found, alumina must reach about 16 per cent. The remaining principal oxides present, in their probable order of abundance, are SiO_2, MgO, FeO, H_2O, and Fe_2O_3.

Whereas the alumina content of the chlorite veins ranges from about 12 to 16 per cent, the surrounding serpentine is practically devoid of Al_2O_3. Although actual analyses are lacking, calculations from the observed modal composition of the serpentine indicate that its alumina content probably does not anywhere much exceed 1 per cent. On the other hand, the clinochlore-actinolite selvages bordering the veins contain up to about 6 per cent Al_2O_3 (corresponding to one-third clinochlore).

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[3] Orcel, M. J., Recherches sur la composition chimique des chlorites: *Bull. Soc. franç. minéral.*, **50,** 424–425 (1927).

Origin of the Veins

It seems certain that the source of most of the alumina in the veins and selvages must be sought outside of the serpentine. Not only is alumina practically lacking in the serpentine itself, but there appears to be no evidence of the introduction of alumina into contact aureoles about serpentines, either here or elsewhere.

The veins are located near bodies of hornblende diorite and hornblende-biotite quartz diorite which are later than the serpentine. The alumina is believed to have been introduced along fracture planes in the serpentine from these or similar plutonic intrusions. The introduction of alumina by igneous emanations is indicated in this district also by the occurrence of andalusite and corundum in a pegmatite dike cutting the metamorphic rocks.[4] It is probable that CaO was also introduced in the actinolite-rich selvages along the veins, although the lime content of the veins themselves is very low.

The introduction of the alumina appears to have been antecedent to the cessation of the orogeny, since the veins are slickensided, and possibly folded. It may, indeed, have preceded the rise of the batholith to its final level, since in the Rocky Hill district clinochlore can be shown to have developed in the serpentine surrounding quartz diorite stocks before the formation of contact metamorphic olivine and enstatite.[5]

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[4] Macdonald, G. A., and Merriam, R., Andalusite in pegmatite from Fresno County, Calif.: *Am. Mineral.*, **23**, 588–594 (1938).

[5] Durrell, C., *op. cit.*

NOTES AND NEWS

DARKENING OF CINNABAR IN SUNLIGHT

Robert M. Dreyer,
California Institute of Technology, Pasadena, Calif.

During the course of an investigation of cinnabar ores, it was found that some specimens show the peculiar tendency to turn surficially black, relatively rapidly, on exposure to sunlight. Insofar as the writer is aware, this rapid darkening is shown by cinnabar from only the following four localities: (1) the Opalite mine and associated deposits located in southeastern Oregon, a few miles north of the town of McDermitt on the northwestern Nevada-Oregon border; (2) the Goldbanks deposit located about thirty five miles south of Winnemucca, Nevada; (3) some of the cinnabar in siliceous sinter at Steamboat Springs, Nevada; and (4) ore from the B and B mine in Esmeralda County, Nevada. The darkening of cinnabar at the third locality is known to the writer only through conversation with Professor V. P. Gianella and that at the fourth locality, through information received from Dr. R. W. Webb. At all four of these localities the cinnabar occurs disseminated through hydrothermal silica formed at or near the surface. At least in the Goldbanks deposit, the cinnabar and silica have been deposited syngenetically and the admixture is so intimate that it is impossible to effect a complete separation of cinnabar from silica. Ransome[1] has stated that all cinnabar darkens on exposure to sunlight. Upon exposure for a long period, this may be true, since it likewise has been noted that cinnabar vermilion used in painting darkens after a number of years.[2] However, within a period of a few months, or a somewhat longer period, this darkening is not characteristic of all cinnabar since the writer has seen a number of museum specimens and open pit exposures which are still bright red after exposure to sunlight for several years. A specimen of cinnabar from the Aurora mine in San Benito County, California, as well as cinnabar concentrated from a specimen collected by Ransome in the Mazatzal Mountains of Arizona were exposed to sunlight for six months without any change being noted.

Table 1 tabulates the results of experiments on natural and artificial red mercuric sulphide.

A specimen of the low grade Opalite ore was mounted in bakelite and polished. The section was then exposed to sunlight in air and the decrease

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[1] Ransome, F. L., Quicksilver: *U. S. Geol. Survey, Mineral Resources* 1917, pt. **1**, 392 (1921).

[2] Mellor, J. W., *A Comprehensive Treatise on Inorganic and Theoretical Chemistry*, **4**, 951.

TABLE 1. EXPERIMENTS ON THE DARKENING OF RED MERCURIC SULPHIDE IN SUNLIGHT

Sample	In air	In water	In 10% KOH	In darkness
Mercuric sulphide prepared by sublimation	Not darkened in 10 weeks	Not darkened in 10 weeks	Not darkened in 10 weeks	
Mercuric sulphide prepared by wet method	Not darkened in 10 weeks	Not darkened in 10 weeks	Not darkened in 10 weeks	
β-HgS	Not darkened in 8 weeks	Not darkened in 10 weeks	Darkened in 8 days	Not darkened in 10 weeks in 10% KOH or in 1 year in air
Cinnabar ore from Aurora mine	Not darkened in 8 months	Not darkened in 10 weeks		
Concentrates of cinnabar ore from Mazatzal Mts.	Not darkened in 8 months	Not darkened in 10 weeks	Darkened in 2 weeks	
Low grade Goldbanks ore	Darkened in Winnemucca and Washington in 5 days Darkened in Pasadena in 8 weeks	Not darkened in 10 weeks in Pasadena	Darkened in 8 weeks in Pasadena	Not darkened in 5 months
High grade Goldbanks ore	Not darkened in 10 weeks in Pasadena, nor in 2 weeks in Winnemucca	Not darkened in 10 weeks in Pasadena	Not darkened in 8 weeks in Pasadena	Not darkened in 5 months
Low grade Opalite ore	Darkened in 2 days	Darkened in 2 days	Darkened in ½ hour	Not darkened in 6 months in air, but darkened in ½ hour in KOH
High grade Opalite ore	Darkened in 4 weeks	Not darkened in 10 weeks	Darkened in 2 days	Not darkened in 6 months in air nor in 2 weeks in KOH

in internal reflection noted every three hours. The internal reflection decreased gradually until none remained after two days. Since the cinnabar itself is dispersed through silica, the character of the darkened compound could not be determined from the polished section.

The experimentally determined relationships are rather confusing, but can be summarized as follows:

(1) Cinnabar in low grade ore darkens on exposure to sunlight more rapidly than that in high grade ore.

(2) When the darkening occurs, alkali seems to accelerate the rate of darkening.

(3) Water appears to decrease slightly the rate of darkening.

(4) The rate of darkening varies greatly for mercuric sulphide prepared in various ways.

(5) All known naturally occurring cinnabar that darkens rapidly occurs in a matrix of hydrothermal silica.

The darkening under discussion involves a change in the color from red to black of a very thin surficial layer of cinnabar. Longer exposures, as noted at the Goldbanks mine, intensifies the darkening, but does not increase the thickness of darkened layer. Heumann[3] states that acids inhibit the darkening; that under pure water the change is very slow; but that under alkaline conditions the darkening occurs in a few minutes, and that cinnabar prepared by the wet method darkens more rapidly than that prepared by sublimation. The writer has been unable to duplicate Heumann's results. Allen and Crenshaw[4] observed that, when cinnabar is heated to 325°, the surface turns black, but that the red color returns when the cinnabar is cooled. If the cinnabar is heated to 445° the darkening is permanent. The surficial change in the color of cinnabar from red to black in sunlight often has been assumed to be a change from cinnabar to metacinnabar. However, the fact that the same surficial darkening is observed when cinnabar is heated (although metacinnabar is a monotropic form which, at high temperatures, is converted to cinnabar) casts doubt on the validity of this assumption. Dr. Schaller[5] has reminded the writer that some metals such as platinum, when precipitated in a very finely divided state, are black. The writer prepared a solution of colloidal mercury by dilution of an alkaline mercuric sulphide complex solution. When this solution is poured over a porcelain surface, a mercury mirror is deposited. When the mercury mirror is wiped off with a cloth the deposit on the cloth is black. There is, therefore, no reason why the darkening of cinnabar could not be the result of the formation of a surficial layer of colloidal mercury in solid solution in the cinnabar. The darkened layer is not removed by nitric acid as it should be were it mercury. However, silver halides, covered with a solution of nitric acid in which metallic silver is soluble, darken on exposure to sunlight. The current theory explaining the darkening of silver halides, therefore, likewise postulates a surficial dispersion of silver as a solid solution in the silver halide[6] since metallic silver in solid solution would not be removed by nitric acid. Despite the long use of photographic emulsions, the exact cause and character of the darkening of silver halides is still not known definitely. One of the difficulties in studying photosynthetic compounds is due not only to the small amount of the synthesized substance which is formed, but also to the fact that very small differences in the medium in which the compound is imbedded cause a wide variation in the photosensitivity of the compound. Although it has long been known that variations in the emulsion cause a great variation in the sensitivity of silver halides to light, the fact was only recently discovered that the sensitivity of the halides is greatly increased by the presence in the emulsion of minute amounts (1:300,000 to 1:1,000,000) of allyl isothiocyanate (C_3H_5CNS—allyl mustard oil).[7] By analogy, it is possible that some minute impurity in the cinnabar or adjacent wall rock might greatly affect the photosensitivity of the cinnabar and explain some of the observed anomalies.

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[3] Heumann, Karl, Veränderung den Zinnobers durch das Licht: *Ber. deut. chem. Gesell.*, **7**, 750–51 (1874).

[4] Allen, E. T., and Crenshaw, J. L., *Am. Jour. Sci.*, 4th series, **34**, 379 (1912).

[5] Schaller, W. T., Personal communication.

ACKNOWLEDGMENTS. The writer wishes to acknowledge the kindness of Drs. H. G. Ferguson, W. T. Schaller, and E. B. Eckel of the U. S. Geological Survey, who have assisted in attempting to ascertain the cause of the darkening of cinnabar on exposure to sunlight. Professors H. J. Fraser and Ian Campbell of the California Institute of Technology have been most generous with their advice during the preparation of this paper for publication.

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[6] Mellor, J. W., *op. cit.*, **3**, 414.

[7] Wall, E. J., *Photographic Emulsions*, 25–7 (1929).

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BOOK REVIEWS

GEMS AND GEM MATERIALS. By Edward Henry Kraus and Chester Baker Slawson. McGraw-Hill Book Company, Inc. Third Edition, 1939. Pages 287.

Growing recognition of the value of the study of gem stones as a cultural subject is shown by the increase in the number of educational institutions offering systematic instruction in this subject in their curricula. In late years jewelers have displayed increased interest in obtaining scientific information relative to their wares in order that they might serve their clientele more efficiently. A marked growth in popular interest in the collecting and polishing of semi-precious stones as a use for leisure has been in evidence where such materials may be collected readily, particularly in the Pacific coast states. To these groups and all those having any interest in the collection, occurrence, properties, and preparation of gem stones the appearance of the third edition of *Gems and Gem Materials* will be a welcome event.

This edition is illustrated with four color plates which for beauty and accuracy of representation are unsurpassed in American publications. In addition there are 344 black and white illustrations which add greatly to the interesting presentation of subject matter. The systematic presentation of the text, which begins with the study of crystal forms and progresses through the physical, optical, and chemical properties of gems and closes with summarized data relative to the properties of individual gem materials, expands the comprehensive plan which was followed in earlier editions. The chapter on cutting and polishing of gems contains an exceptionally useful description of this art with the only detailed explanation yet published of the relationship of the atomic structure of the diamond to the technique of cutting. The chapter on manufactured gems, based on the senior author's investigations in Europe, supplies an unusually thorough treatment of this subject which must be understood by all students of gem materials.

The teacher charged with instruction in gem stones will find this text unequaled due to its arrangement and comprehensive treatment of all the factors related to gems. Those having either a scientific or general interest in gem materials will find the text to be accurate in detail and unusually readable due to its pleasing format. Price has been established at $3.50 in spite of the expense associated with the introduction of color.

W. M. Myers

THE STONE INDUSTRIES. By Oliver Bowles. Second Edition, 1939. McGraw-Hill Book Company, Inc. Price $5.00.

With the exception of statistical data which have been brought up to date, the second edition of *The Stone Industries* differs but little from the first edition of 1934. It continues to be the only single publication adequately covering the occurrence, technology and utilization of ornamental, dimension and crushed stone. For this reason it is particularly useful to investigators in this field and to those who have occasion to give instruction in this subject.

W. M. Myers

PROCEEDINGS OF SOCIETIES

NEW YORK MINERALOGICAL CLUB, INC.

The American Museum of Natural History, New York City.

Meeting of May 17, 1939.

The meeting was called to order at 8:10 P.M. by First Vice-President Lee with 58 members and guests present. At this final meeting of the year, the annual reports of the officers were presented to the members. Following the brief business meeting the Chairman introduced the speaker of the evening, an honorary member of the Club, Dr. Waldemar T. Schaller, of the United States Geological Survey. He addressed the Club upon the "Buried Deposits of Borax in California." In his talk he described the remarkable deposits of kernite which are the present principal source of borax in this country and described the interesting experiments bearing on its formation performed in the laboratory with final success. From this he gave his theory of the manner of its formation in California and showed lantern slides to bear out his postulates. The meeting adjourned at 9:50 P.M. following the appointment by incoming President Lee of George E. Ashby, Cecil H. Kindle and Walter E. Kuenstler to the Membership Committee; and L. N. Yedlin and M. Allen Northup to the Excursion Committee.

F. H. Pough, *Secretary*

Mr. George Switzer, graduate student at Harvard University, has been appointed teaching fellow in mineralogy at Stanford University for 1939–40.